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TWO-YEAR EVALUATION OF GROUNDWATER EXTRACTION SYSTEM AT THE HELENA LANDFILL HELENA, MONTANA

Prepared For:
CITY OF HELENA
HELENA, MONTANA



Hydrometrics, Inc.[®]
consulting scientists, engineers and contractors

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MONTANA
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COMMUNITY SERVICES BUREAU

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TWO-YEAR EVALUATION OF GROUNDWATER EXTRACTION SYSTEM AT THE HELENA LANDFILL

HELENA, MONTANA

Prepared for:

Mr. John Rundquist
Director of Public Works
City of Helena
Helena, MT 59601

Prepared by:

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January 2003

January 31, 2003

Mr. John Rundquist
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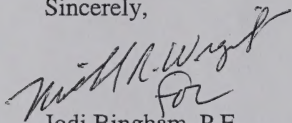
FEB 04 2003

MONTANA
DEPT. OF ENVIRONMENTAL QUALITY
COMMUNITY SERVICES BUREAU

Dear John,

Please find enclosed for your review a copy of the report "Two-Year Evaluation of Groundwater Extraction System at the Helena Landfill." A copy of this report was also sent to Pat Crowley at the Montana Department of Environmental Quality. If you have any questions concerning this report, please do not hesitate to call.

Sincerely,



Jodi Bingham, P.E.
Environmental Engineer/Chemist

Enclosure

c: Pat Crowley, MDEQ (w/enclosure)
Mike Wignot, Hydrometrics

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TWO-YEAR EVALUATION OF GROUNDWATER EXTRACTION SYSTEM AT THE HELENA LANDFILL HELENA, MONTANA

1.0 INTRODUCTION

The closed Helena landfill has impacted groundwater quality beneath and downgradient of the site. Beginning in 1995, a series of corrective measures assessments were completed to assess the impact on groundwater quality and determine the most effective remediation options. A phased approach was used based on discussions with the Montana Department of Environmental Quality (MDEQ) and City of Helena representatives. Most recently, a groundwater extraction system was installed along the northern boundary of the landfill in December 1999 and began operation in June 2000. This system was installed to intercept groundwater containing volatile organic compounds (VOCs), treat the extracted groundwater, and land apply the treated water for evapotranspiration at the Bill Roberts Golf Course. The MDEQ granted a two-year evaluation period in which to operate the system and evaluate its effectiveness. The evaluation period ended in June 2002 and this report summarizes all remediation alternatives currently in-place, the results of the monitoring (including Fall 2002 data), the effectiveness of the current remediation and recommendations for further action.

1.1 SITE DESCRIPTION

The Helena Landfill comprises three landfilled areas totaling approximately 37 acres and is located in T10N, R3W, Sections 19 and 30. The Helena Landfill is bordered to the west by Carroll College and Elk River Concrete, to the north by Bill Roberts Municipal Golf Course, to the east by Memorial Park and to the south by Lyndale Avenue. A Vicinity Map is shown in Figure 1-1. Figure 1-2 shows the landfill area, including the City's property boundary, and the relative compliance boundary (RCB) for groundwater evaluation at the landfill. The RCB is defined in ARM 16.14.708 as 150 meters beyond the waste management unit boundary on land owned by the owner of the disposal unit.



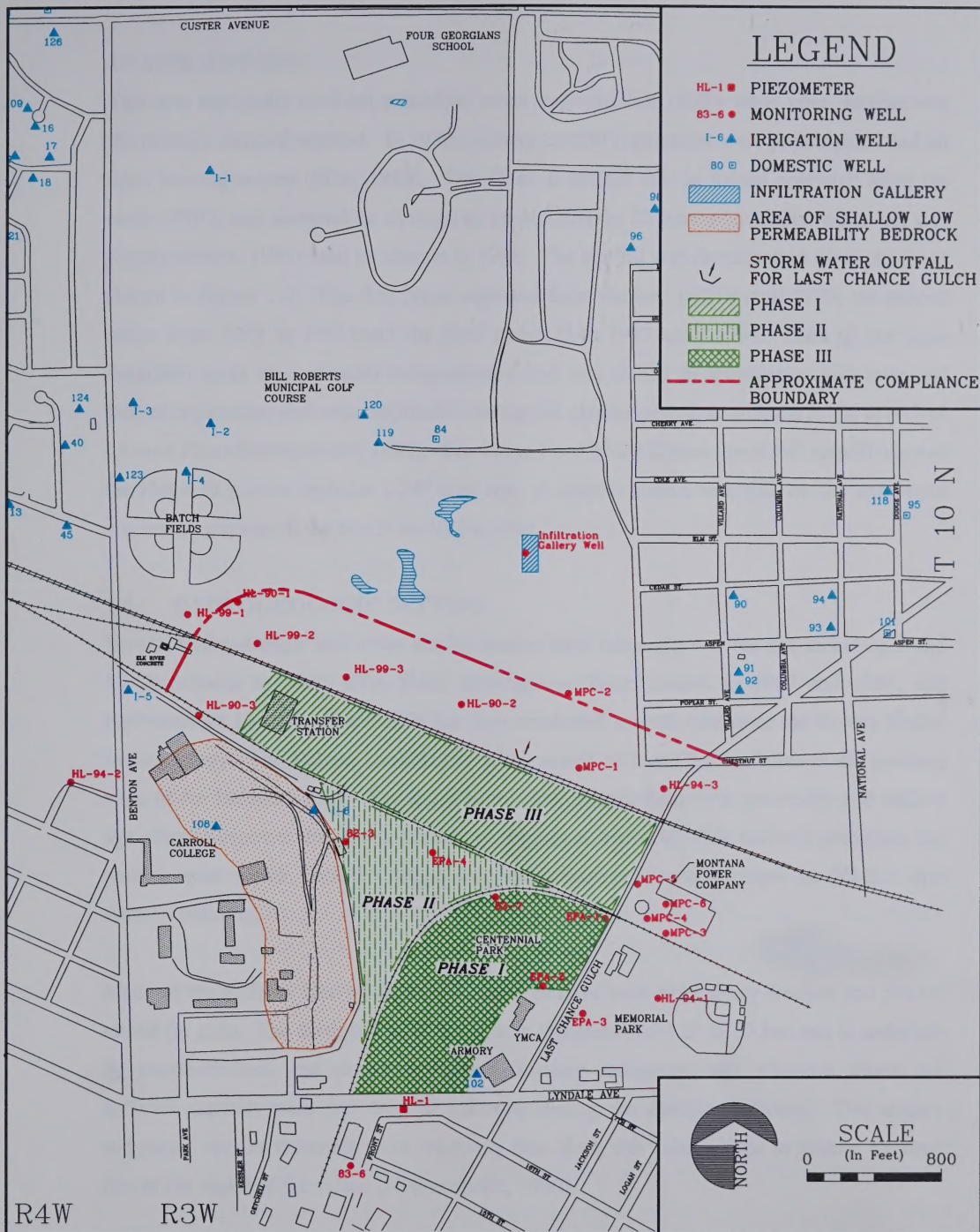
TWO-YEAR EVALUATION OF
GROUNDWATER EXTRACTION SYSTEM
AT THE HELENA LANDFILL
HELENA, MONTANA

VICINITY MAP

FIGURE

1-1





TWO-YEAR EVALUATION OF
GROUNDWATER EXTRACTION SYSTEM
AT THE HELENA LANDFILL
HELENA, MONTANA

STUDY AREA WITH
PROPERTY AND COMPLIANCE
BOUNDARIES

FIGURE

1-2



1.2 SITE HISTORY

This area reportedly received municipal waste since the late 1800's when open burning was the primary disposal method. In 1970, sanitary landfill regulations were promulgated and all open burning ceased (EPA, 1989). This Class II landfill was in formal operation since the early 1970's and accepted an average of approximately 80 tons of domestic waste per day (Hydrometrics, 1991) until its closure in 1994. The landfill was developed in three phases as shown in Figure 1-2. The first phase operated from the late 1800's until 1979, the second phase from 1979 to 1983, and the third phase from 1983 until 1994. Each of the three landfilled areas was operated independently and was closed in accordance with state and federal regulations that were applicable during the closure period as outlined in the approved Closure Plan (Hydrometrics, 1993). The Phase I and Phase II areas have a 6" topsoil cap and the Phase III portion includes a 24" clay cap. A transfer station was built on site and began conveying garbage to the Site E landfill in 1994.

1.4 HYDROGEOLOGIC SETTING

Several hydrogeologic and water quality studies have taken place at the site including F and M Consultants in 1982, EPA Field Investigative Team studies in 1987 and 1989, and Hydrometrics in 1990. The USGS has also conducted several studies of the Helena Valley hydrogeology. The Helena Landfill lies at the mouth of Last Chance Gulch at the southern edge of the Helena Valley. The gulch in this area is underlain with quaternary and tertiary age alluvial deposits that are in contact with igneous bedrock. This bedrock comprises the mound upon which Carroll College sits, and limestone deposits below the YMCA and Armory building.

Much of the surficial alluvial deposits in the area have been extensively dredged and placer-mined for gold. The dredged material varies in thickness from 25 to 50 feet and is underlain by unconsolidated and semi-consolidated Tertiary sediments, and alluvium where the surficial deposits were too deep to excavate during the dredging process. The tertiary sediments vary in thickness from relatively thin along the valley edges to several hundred feet in the center of the valley (Hydrometrics, 1990).

Groundwater at and near the Helena Landfill occurs in both the alluvium and the underlying bedrock. North of the landfill, groundwater also occurs in dredge piles left from historic mining activities, and in the semi-consolidated tertiary sediments. Because of the heterogeneous nature of the geology, most groundwater flow is likely through a complex network of higher permeable zones and layers.

An inventory of monitoring wells and private irrigation and domestic wells is shown on Figure 1-3 which also contains a potentiometric map showing the groundwater table during June 2002. Groundwater flow in the landfill area is generally north/northwest with an average hydraulic gradient of about 0.03 ft./ft. Depth to groundwater across the landfill area varies from approximately 20 to 50 feet. Groundwater velocity in the vicinity of the landfill is estimated at 2 to 3 feet per day (Hydrometrics, 1990). A more detailed description of the Helena Landfill hydrogeology is contained in "Hydrogeologic Investigation of the City of Helena Landfill" (Hydrometrics, 1990).

1.3 NATURE AND EXTENT OF CONTAMINATION

The City of Helena has performed extensive groundwater monitoring to determine the nature and extent of groundwater contamination associated with the landfill. Fourteen groundwater monitoring wells, eight domestic wells, two irrigation wells, and the infiltration gallery well are monitored semiannually in June and December (during high and low water levels) and the data statistically evaluated. In addition, a set of quarterly groundwater samples including five groundwater monitoring wells and one domestic well is collected in March and September to monitor the effectiveness of the implemented corrective measures. The samples are collected and analyzed in accordance with the Montana Department of Environmental Quality (MDEQ) approved sampling and analysis plan (Hydrometrics, 1994).

Statistical evaluations have been performed for this site semiannually since 1993 and the following conclusions have been reached based on the results of those evaluations:

- Chlorinated hydrocarbons are present in groundwater downgradient of the landfill as described in the semi-annual statistical evaluations of groundwater quality data.



SITE CODE	DTWL	MPE	SWL
Jun-02			
83-6	12.17	3990.89	3978.72
EPA-1	47.55	3981.08	3933.53
HL-90-1	58.63	3942.48	3883.85
HL-90-2	52.46	3950.96	3898.50
HL-90-3	62.18	3958.29	3896.11
HL-94-1	58.97	3994.04	3935.07
HL-94-2	28.33	3966.19	3937.86
HL-94-3	36.79	3967.38	3930.59
*HL-99-1	74.81	3943.15	3868.34
*HL-99-2	86.05	3945.75	3859.70
*HL-99-3	66.27	3948.05	3881.78
INF. GALLE	8.50	3918.89	3910.39
**I-1	95.00	3899.59	3804.59
MPC-1	23.43	3946.08	3922.65
MPC-2	17.31	3936.09	3918.78
MPC-5	58.30	3989.04	3930.74

- * MEASUREMENTS TAKEN A WEEK BEFORE OTHERS.
 ** ESTIMATED BASED ON PREVIOUS YEARS' MEASUREMENTS.



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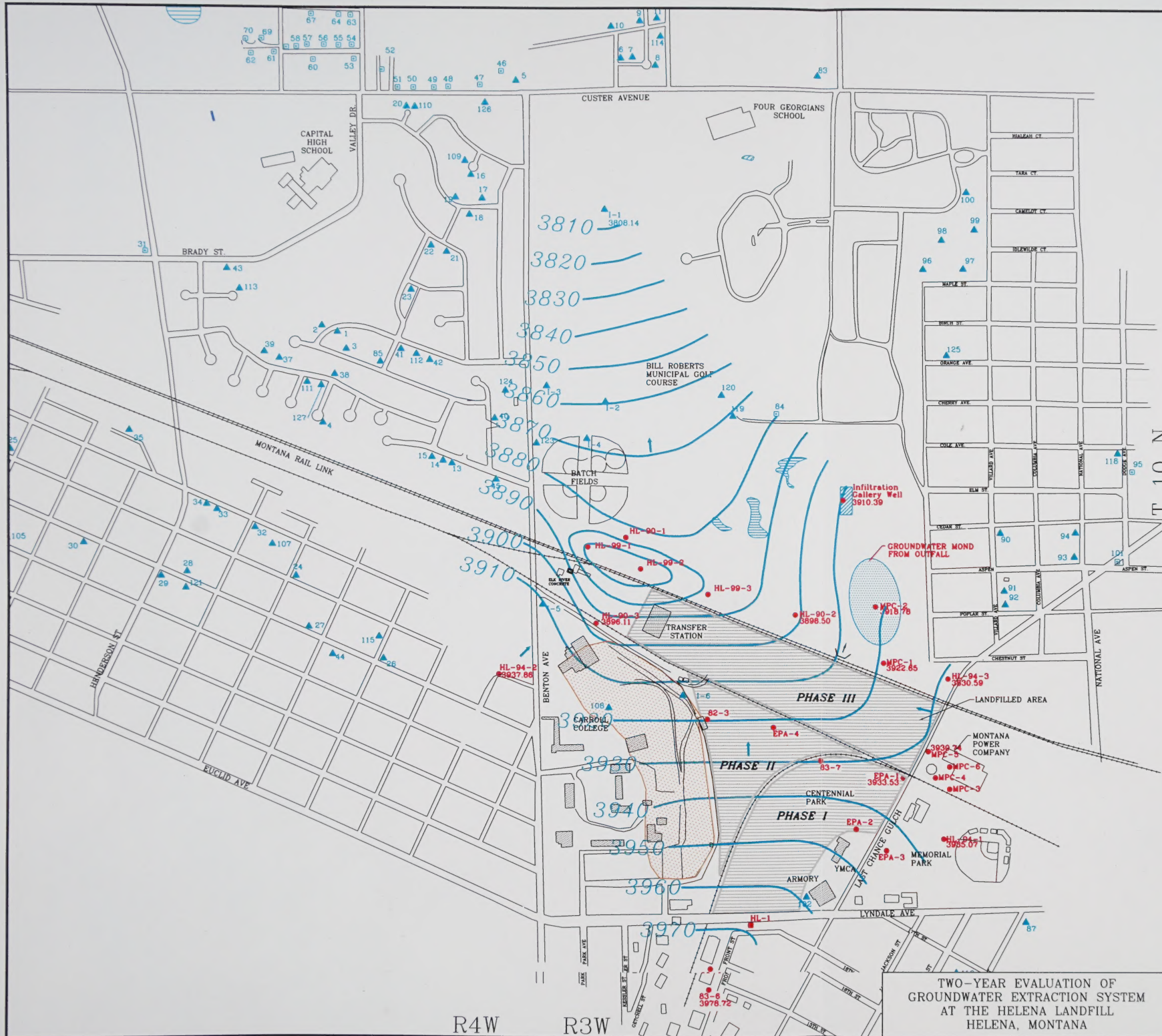
LEGEND

- 1 ■ PIEZOMETER
- MONITORING WELL
- 6 ▲ IRRIGATION WELL
- 30 □ DOMESTIC WELL
- INFILTRATION GALLERY (GROUNDWATER COLLECTION SYSTEM)
- AREA OF SHALLOW LOW PERMEABILITY BEDROCK
- POTENTIOMETRIC CONTOUR LINE
- INFERRED GROUNDWATER FLOW DIRECTION
- STORM WATER OUTFALL FOR LAST CHANCE GULCH

WELL INVENTORY AND
 JUNE 2002
 POTENTIOMETRIC SURFACE

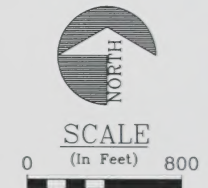
FIGURE

1-3



SITE CODE	DTWL	MPE	SWL
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* MEASUREMENTS TAKEN A WEEK BEFORE OTHERS.
 ** ESTIMATED BASED ON PREVIOUS YEARS' MEASUREMENTS.



LEGEND

- HL-1 ■ PIEZOMETER
- 83-6 ● MONITORING WELL
- I-6 ▲ IRRIGATION WELL
- 80 □ DOMESTIC WELL
- INFILTRATION GALLERY (GROUNDWATER COLLECTION SYSTEM)
- AREA OF SHALLOW LOW PERMEABILITY BEDROCK
- 3900 — POTENTIOMETRIC CONTOUR LINE
- INFERRED GROUNDWATER FLOW DIRECTION
- STORM WATER OUTFALL FOR LAST CHANCE GULCH

TWO-YEAR EVALUATION OF
GROUNDWATER EXTRACTION SYSTEM
AT THE HELENA LANDFILL
HELENA, MONTANA

WELL INVENTORY AND
JUNE 2002
POTENTIOMETRIC SURFACE

FIGURE

1-3

- Two groundwater constituents regularly exceed the Maximum Contaminant Level (MCL, federal drinking water standard) in one or more downgradient wells: nitrate + nitrite as N (nitrate) and tetrachloroethene (PCE).
- PCE is the chlorinated organic compound of greatest concern due to MCL exceedances; however, concentrations of PCE are decreasing over time in well EPA-1, the well that has historically shown the highest concentrations.
- Elevated nitrate concentrations exist both upgradient and downgradient of the landfill at similar levels.

In order for a chemical constituent to be considered a Contaminant of Concern for corrective measures consideration, it must meet the following criteria:

- The constituent must be detected in downgradient wells at a statistically significant concentration over levels found in upgradient wells, and
- The constituent must be present at the relative point of compliance at a concentration above the Ground Water Protection Standard (GWPS) as defined in ARM 16.14.708 (5).

In summary, a detected constituent is only a Contaminant of Concern when it is attributable to the landfill and detected at or outside the relative compliance boundary at concentrations exceeding the groundwater protection standard. Using these criteria, PCE was determined to be a Contaminant of Concern for the Helena Landfill and thus required a Corrective Measures Assessment (CMA). Implementation of corrective measures was conducted in a phased approach where one measure was implemented and its effectiveness evaluated before additional corrective measures were added. The original CMA (Hydrometrics, 1995) was completed by Hydrometrics in 1995 and implemented in 1995. The First Addendum to the CMA was submitted in 1996 (Hydrometrics, 1996) and the YMCA/Armory gas extraction system was built in fall 1997 and spring 1998. The Second Addendum to the CMA was completed in 1999 (Hydrometrics, 1999b) and the groundwater extraction system was installed in December 1999 and spring 2000. All these are further described in Section 2 of this report.

2.0 CORRECTIVE MEASURES ASSESSMENT

Hydrometrics prepared the CMA and its addendums to fulfill the requirements set forth in the Administration Rules of Montana (ARM) 16.14.708 for assessing potential corrective measures for groundwater contamination at landfills in Montana. Based on this assessment, preferred mitigative alternatives that were protective of human health and the environment were selected and implemented.

2.1 CORRECTIVE MEASURES OBJECTIVES

The process of developing and evaluating corrective measure alternatives for remediation of the groundwater at the Helena Landfill began by establishing the objectives which the selected remedy would be expected to achieve. The objectives which selected corrective measures were expected to achieve are specified in ARM 16.14.708 (7) (b) and include the following:

- Protection of Human Health and the Environment;
- Attainment of Groundwater Protection Standards;
- Control of Source Area;
- Compliance with Waste Management Practices; and
- Approval by MDHES.

2.2 PRE-EXISTING CORRECTIVE MEASURES IMPLEMENTED

Several corrective measures were implemented by the City following the submission of the initial hydrogeological characterization presented in 1990 (Hydrometrics, 1990). These included continuing groundwater monitoring, enforcing existing institutional controls limiting use and access of impacted groundwater, closing the landfill, installing a clay cover on newest landfilled area, and extending the Last Chance Gulch storm drain north of the landfill away from the landfill.

2.2.1 Groundwater Monitoring

Continued groundwater monitoring is required under ARM 16.14.701. The current groundwater monitoring program includes analyzing samples from 27 monitoring and residential wells for 250 chemical constituents two times every year. This program is detailed in the Helena Landfill Closure Plan (Hydrometrics, 1993) and the approved Sampling and Analysis Plan (Hydrometrics, 1994). Monitoring will provide advance warning of degrading water quality or indicate that implemented corrective measures are resulting in improved groundwater quality and attainment of groundwater protection standards.

2.2.2 Institutional Controls

Existing city ordinances require each residence within city limits to connect to the city water supply for potable water use (Title 3, Chapter 2, Section 10). This ordinance greatly reduces the potential for human exposure by providing an alternative potable water source other than the impacted groundwater. Additional wells within the city limits also are prohibited by a ban on well drilling within city limits (Title 3, Chapter 11), thereby restricting access to impacted groundwater. Title 3, Chapter 11, Section 3 requires that there be no cross-connection between any private wells and the City water distribution system. These institutional controls are protective of human health by limiting potential exposure pathways.

2.2.3 Landfill Closure

Closure of the landfill in 1994 prevented addition of any waste to the site and controlled the source area by limiting its volume. This measure controlled and limited potential future releases of all types of contaminants, not just VOCs.

2.2.4 Clay Capping

Release of contaminants was further limited by capping the most recently active portion of the landfill (Phase III). The mobility of any potential contaminants existing as waste in the landfill is reduced now that precipitation and surface water could no longer generate significant amounts of landfill leachate.

2.2.5 Storm Drain Extension

The Last Chance Gulch storm sewer previously discharged just north of the landfill boundary. It was suspected that infiltrating storm water runoff was mounding beneath and into the landfill generating leachate. This drain was extended 150 feet beyond the northern boundary of the landfill to eliminate this problem.

2.3 ORIGINAL CORRECTIVE MEASURES ASSESSMENT

The original CMA (Hydrometrics, 1995) used a three-tiered screening methodology to develop a set of applicable alternatives, evaluate each according to required criteria, and propose a preferred remedy. Six remedial alternatives were presented and developed in the original CMA. These alternatives included the existing corrective measures (discussed in Section 2.2), landfill gas extraction and treatment, in-situ air sparging, groundwater extraction and discharge to POTW for treatment, groundwater extraction with evaporation and seasonal discharge to POTW, and groundwater extraction, direct treatment and discharge. The first alternative, evaluating the effectiveness of the existing corrective measures was selected as the preferred alternative.

2.4 FIRST ADDENDUM TO CMA

In the first addendum to the CMA (Hydrometrics, 1996), an evaluation of the 1995 groundwater quality data was presented. This data indicated concentrations of nitrate and PCE that still exceeded the MCL. Therefore, the implementation of additional corrective measures as outlined in the original CMA was considered. Alternative 2, landfill gas extraction and treatment (Section 5.2 of the CMA) was selected as the next preferred alternative to reduce risks to water quality as well as increase protection of buildings from migrating methane gas.

All municipal landfills generate landfill gases as long as organic wastes remain available for biological decomposition. The primary landfill gas generated at the Helena Landfill is methane. Under equilibrium, all VOCs have partitioning constants that govern the fraction of the constituent existing as vapor and dissolved in groundwater. The removal of methane and other landfill gases lowers the concentrations of VOCs existing as landfill gases and

causes more VOCs to volatilize from the dissolved groundwater plume. Extraction would also volatilize VOCs existing as liquids within the buried solid waste. It was expected that even small reductions in dissolved VOCs were likely to have an impact sufficient to attain groundwater protection standards at the relative compliance boundary.

The landfill gas extraction system consists of six extraction wells installed within the limits of the buried solid waste as shown in Figure 3-1. The system focuses primarily on areas of public safety concern with respect to methane, mainly the YMCA and Armory buildings. In addition, the system has the potential to remove additional volatile landfill contaminants and improve groundwater quality in this area. An explosion-proof blower places a vacuum on these wells and the pressure gradient causes landfill gas to flow to the wells and be removed from the landfill area. The blower effluent is treated in a drum of granular activated carbon before being released out the vent house stack.

Construction of the gas extraction system was begun in November 1997 and was completed in June of 1998. Operation of the system began on May 12, 1998. Monthly monitoring of system temperatures and pressures were used to optimize system performance. Gas samples were collected from the gas extraction system header on a monthly basis to monitor the quantity of landfill contaminants being removed. Although methane and several other VOCs were being extracted at a significant rate, the system failed to remove measurable concentrations of PCE, the main groundwater constituent of concern. Additionally, although groundwater quality improved, the December 1998 and June 1999 sampling results indicated that concentrations of PCE still exceeded the MCL in downgradient compliance wells. Therefore, in August 1999, a Second Addendum to the CMA (Hydrometrics, 1999b) was submitted to MDEQ.

2.5 SECOND ADDENDUM TO CMA

The already existing corrective actions and those implemented as part of the original CMA and the Addendum to the CMA improved groundwater quality, but not sufficiently to bring PCE levels in the compliance wells (wells HL-90-1, HL-90-2, and MPC-1) below the MCL. Additionally, groundwater quality trends in those wells did not show a decreasing trend in

PCE concentrations. Therefore, at the request of the City and MDEQ, two of the remaining four remedial alternatives investigated in the original CMA, but not selected for implementation, were selected for reevaluation as potential corrective actions and submitted as the Second Addendum to the CMA (Hydrometrics, 1999b). The first was in-situ air sparging with optional vapor extraction (Section 5.3 of the CMA) and the second was groundwater extraction and treatment (Section 5.5 of the CMA). The results of these reevaluations are presented below.

2.5.1 Air sparging

Air sparging is a technology in which air is injected into the groundwater to volatilize residual contaminants in-situ. Air is injected into the saturated zone through wells installed below the water table and the air bubbles migrate upward through the groundwater to the unsaturated zone. As the air bubbles pass through the contaminated water, volatile organic compounds (VOCs) in the water enter the air and are transported to the unsaturated zone. The air containing the VOCs is then either extracted using a vapor extraction well, or allowed to naturally migrate to the surface and enter the atmosphere.

The effectiveness of the technology is primarily a function of the strippability and/or volatility of the contaminants and the nature and extent of the air pathways in the soil. All of the VOCs detected in the groundwater leaving the Helena Landfill boundaries met the criteria for strippability and volatility indicating that these compounds would be highly amenable to air sparging. To evaluate the nature and extent of the air pathways, all available wells logs for the area were studied. The geology in this area is highly variable in both the saturated and unsaturated zones with layers of fairly permeable materials (sands and gravels) interspersed with layers containing high percentages of fine materials (silt and clay). Air sparging is highly sensitive to variability in the vertical stratigraphy, particularly when a less permeable layer overlies a more permeable layer. In these cases, air bubbles containing contaminants and migrating through the more permeable layer are unlikely to pass through the less permeable layer, but will migrate laterally instead, and in worst cases, actually spread the contamination. Due to the variable stratigraphy in this area, it was determined that air sparging may not be effective and could produce lateral spreading of the PCE plume.

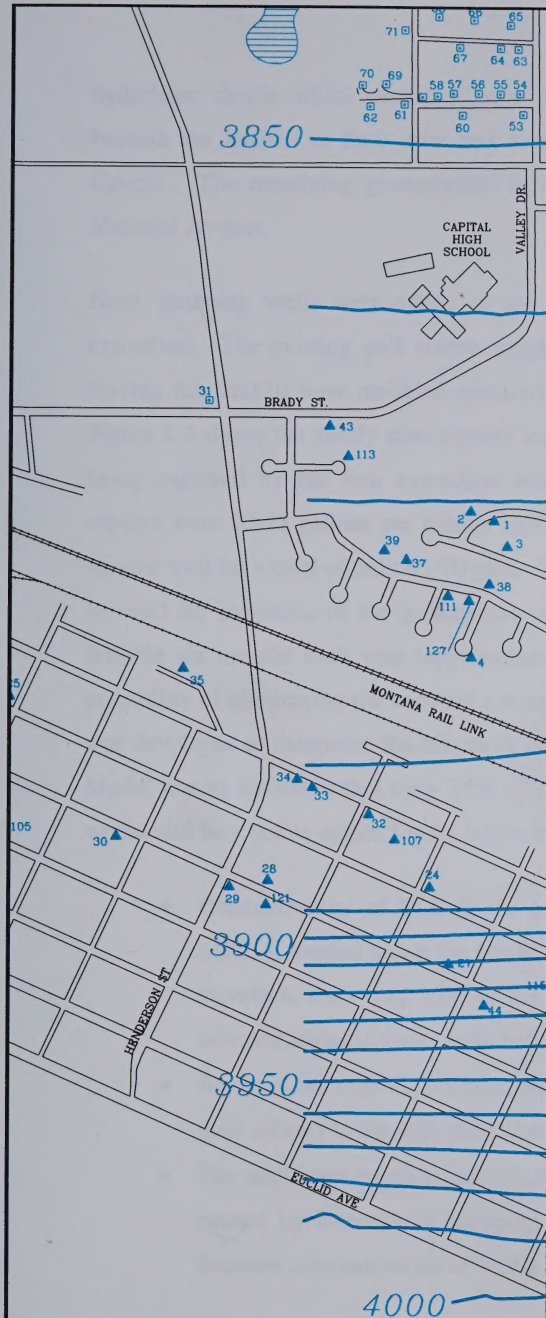
2.5.2 Groundwater Extraction

As an alternative to treating the water in-situ, the water could be extracted, treated, and then reinfiltrated back to the aquifer. In the case of the Helena Landfill, it could be used to replace irrigation water for Bill Roberts Golf Course or Centennial Park. Since the VOCs are easily removed from the extracted water, the feasibility and cost-effectiveness of this alternative depended on the number of wells and pumping rates required to capture the plume leaving the northern boundary of the landfill. To evaluate the potential effectiveness, associated costs, and regional implications of a groundwater extraction system, a groundwater flow or hydrologic model was developed.

2.5.2.1 Hydrologic Model

The hydrologic model was developed using the computer software MODFLOW. A detailed discussion of the model setup and copies of the model inputs and outputs are included in a report titled "Evaluation of Groundwater Extraction Remediation Alternative and the Helena Landfill," (Hydrometrics, 1999a). To model the groundwater system in the area of the Helena Landfill, a grid was assigned to the area of interest including the landfill site and the surrounding areas. Next, model parameters such as hydraulic conductivity, transmissivity, and the depth to bedrock were assigned to each block of the grid using available well logs and pump test data. The model was then "calibrated" by varying these input parameters and the recharge values associated with the golf course, soccer fields and stormwater outfall within acceptable ranges to reproduce the existing water table. The potentiometric contours predicted by the model are shown on Figure 2-1 and can be compared with the existing potentiometric surface shown in Figure 1-2.

The groundwater flow paths leaving the landfill were predicted using a particle-tracking model that traces the flow path of water particles through the groundwater system. A particle was placed in each cell of the model along the northern edges of the Phase I and Phase II landfills and then these particles were tracked over a period of 100 years. Figure 2-1 shows the landfilled area and the path each water particle traveled. A groundwater mound resulting from a stormwater outfall that discharges on the north side of the landfilled area produces a



SCALE
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LEGEND

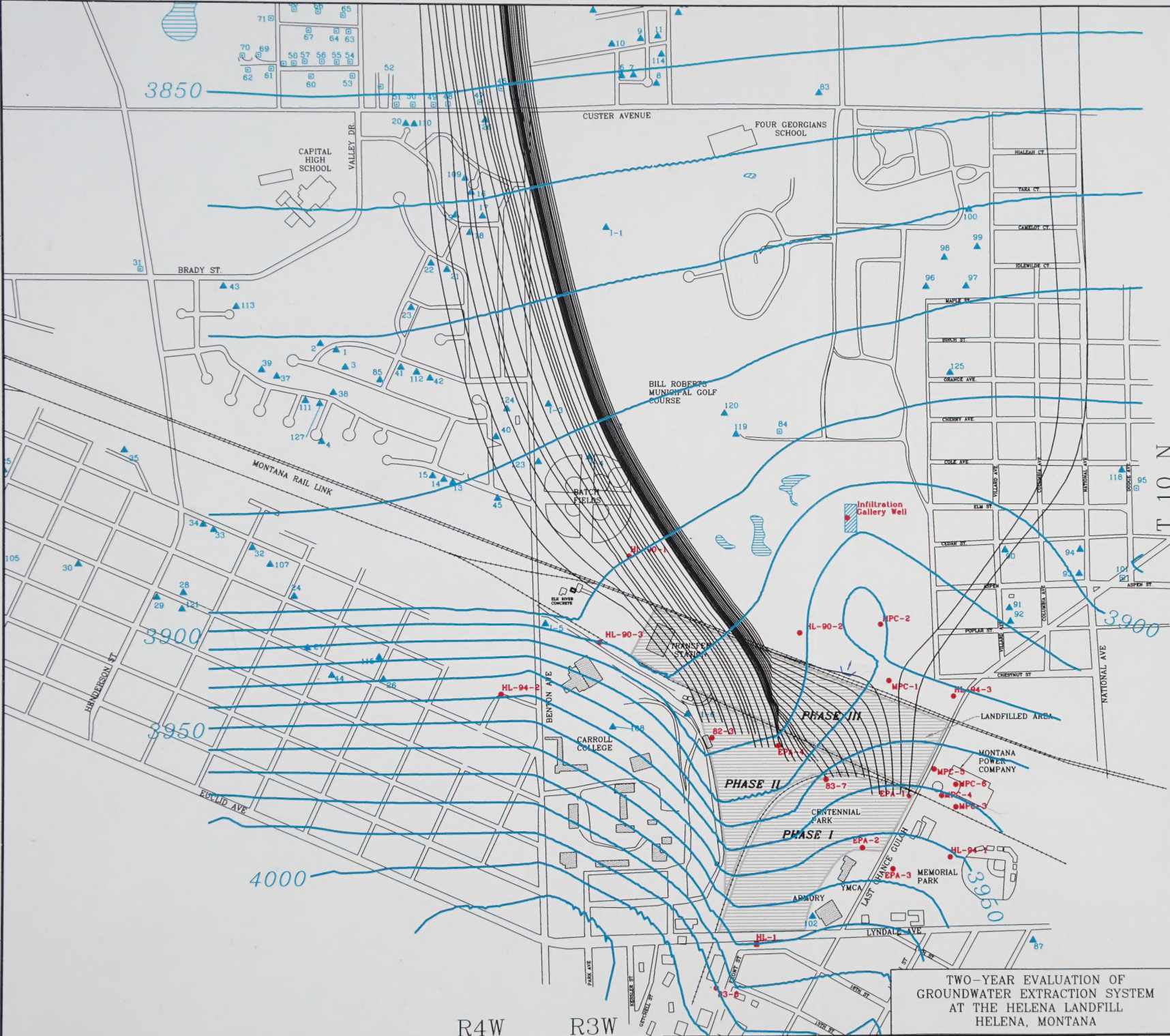
- L-1 ■ PIEZOMETER
- 3-6 ● MONITORING WELL
- 1-6 ▲ IRRIGATION WELL
- 80 □ DOMESTIC WELL
- ▨ INFILTRATION GALLERY (GROUNDWATER COLLECTION SYSTEM)
- GROUNDWATER POTENTIOMETRIC CONTOUR PREDICTED BY MODEL
- GROUNDWATER FLOW PATH PREDICTED BY MODEL
- STORM WATER OUTFALL FOR LAST CHANCE GULCH

GROUNDWATER FLOW PATHS
PREDICTED BY MODEL

FIGURE

2-1





SCALE
(In Feet) 800
0 1 2 3 4 5 6 7 8 9 10

LEGEND

- HL-1 ■ PIEZOMETER
- 83-6 ● MONITORING WELL
- 1-6 ▲ IRRIGATION WELL
- 80 □ DOMESTIC WELL
- INFILTRATION GALLERY (GROUNDWATER COLLECTION SYSTEM)
- GROUNDWATER POTENTIOMETRIC CONTOUR PREDICTED BY MODEL
- GROUNDWATER FLOW PATH PREDICTED BY MODEL
- STORM WATER OUTFALL FOR LAST CHANCE GULCH

TWO-YEAR EVALUATION OF
GROUNDWATER EXTRACTION SYSTEM
AT THE HELENA LANDFILL
HELENA, MONTANA

GROUNDWATER FLOW PATHS
PREDICTED BY MODEL

FIGURE

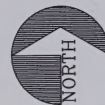
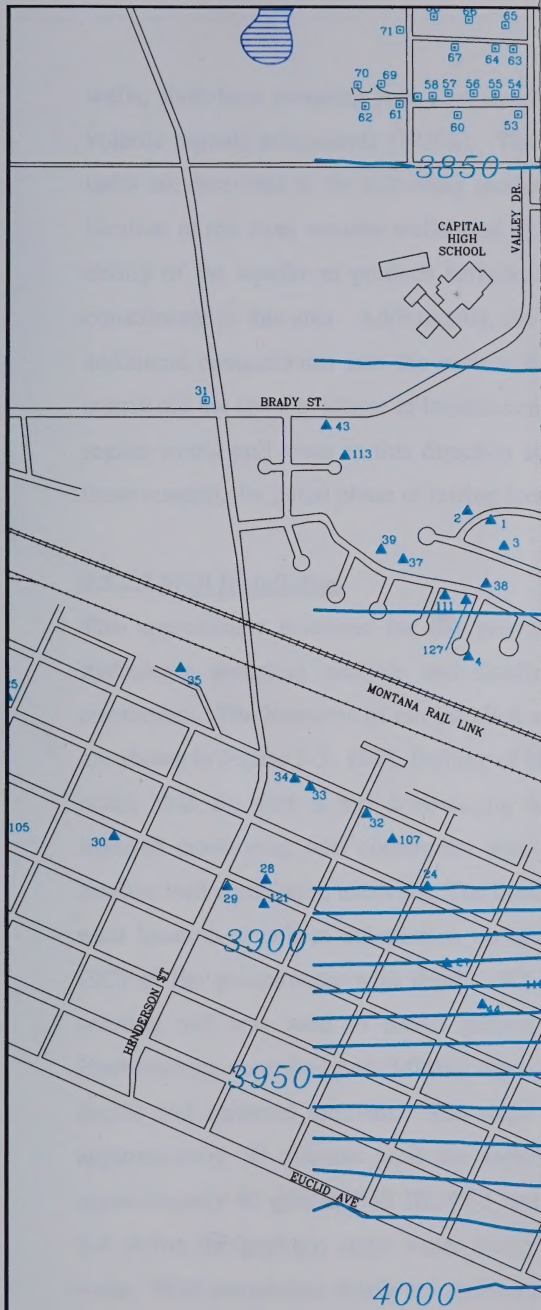
2-1

hydrologic divide which causes a large percentage (>95%) of the groundwater flowing beneath the landfill to flow west and north along the western edge of Bill Roberts Golf Course. The remaining groundwater (<5%) flows east and then generally north along National Avenue.

Next, pumping wells were added to the model to simulate the effects of groundwater extraction. The existing golf course irrigation wells were also included. Water particles leaving the landfill were modeled again with four of the landfill pumping wells turned on. Figure 2-2 shows the steady state capture scenario with all water particles leaving the landfill being captured by the four extraction wells. The pumping rates required for complete capture were 20-25 gallons per minute (gpm) for the three western wells and 5 gpm for the eastern well for a total of only 65-70 gpm. The City proposed that the extracted groundwater be used for irrigation of the golf course or Centennial Park. However, irrigation is only feasible six months each year (approximately April through September). To evaluate the possibility of eliminating the need for a winter treatment option, a 180-day pumping scenario was developed to determine the effects of only extracting water during the irrigation months. Model results indicated that only 75% of the water particles were captured; however, this would still be a viable option for the following reasons:

- Concentrations of PCE in the compliance wells (wells HL-90-1, HL-90-2, and MPC-1, located along the northern landfill boundary) were less than 0.020 mg/L; therefore, removing 75% of the contaminated water may be sufficient to bring concentrations in these wells below the MCL of 0.005 mg/L.
- Because the organic contaminants move slower than the water particles due to their affinity to the soil, more than 75% of these particles may be captured.
- The additional mixing and aeration of the groundwater within the capture zone caused by intermittent pumping of the extraction wells would help to further decrease concentrations of VOCs in the groundwater.

To further evaluate this option, a field investigation was conducted to ascertain exact field conditions and to provide information required to complete a full-scale design. The field investigation consisted of the installation and development of three groundwater recovery



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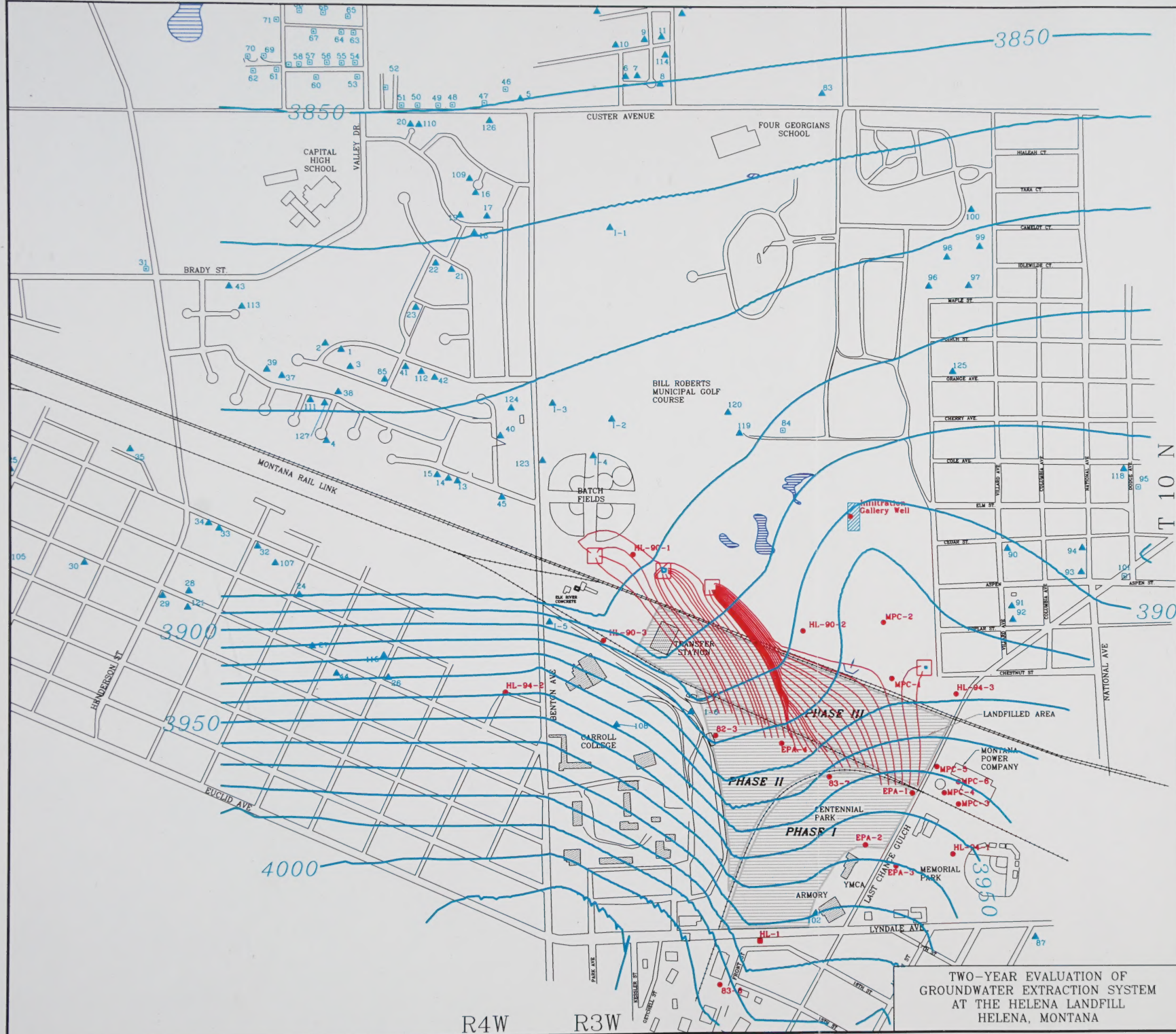
- L-1 ■ PIEZOMETER
- 3-6 ● MONITORING WELL
- 1-6 ▲ IRRIGATION WELL
- 80 □ DOMESTIC WELL
- PROPOSED EXTRACTION WELL
- ▨ INFILTRATION GALLERY (GROUNDWATER COLLECTION SYSTEM)
- GROUNDWATER POTENTIOMETRIC CONTOUR PREDICTED BY MODEL
- GROUNDWATER FLOW PATH PREDICTED BY MODEL
- ↘ STORM WATER OUTFALL FOR LAST CHANCE GULCH

STEADY-STATE
CAPTURE SCENARIO

FIGURE

2-2





- LEGEND**
- HL-1 ■ PIEZOMETER
 - 83-6 ● MONITORING WELL
 - I-6 ▲ IRRIGATION WELL
 - 80 □ DOMESTIC WELL
 - PROPOSED EXTRACTION WELL
 - ▨ INFILTRATION GALLERY (GROUNDWATER COLLECTION SYSTEM)
 - GROUNDWATER POTENTIOMETRIC CONTOUR PREDICTED BY MODEL
 - GROUNDWATER FLOW PATH PREDICTED BY MODEL
 - ↘ STORM WATER OUTFALL FOR LAST CHANCE GULCH

TWO-YEAR EVALUATION OF
GROUNDWATER EXTRACTION SYSTEM
AT THE HELENA LANDFILL
HELENA, MONTANA

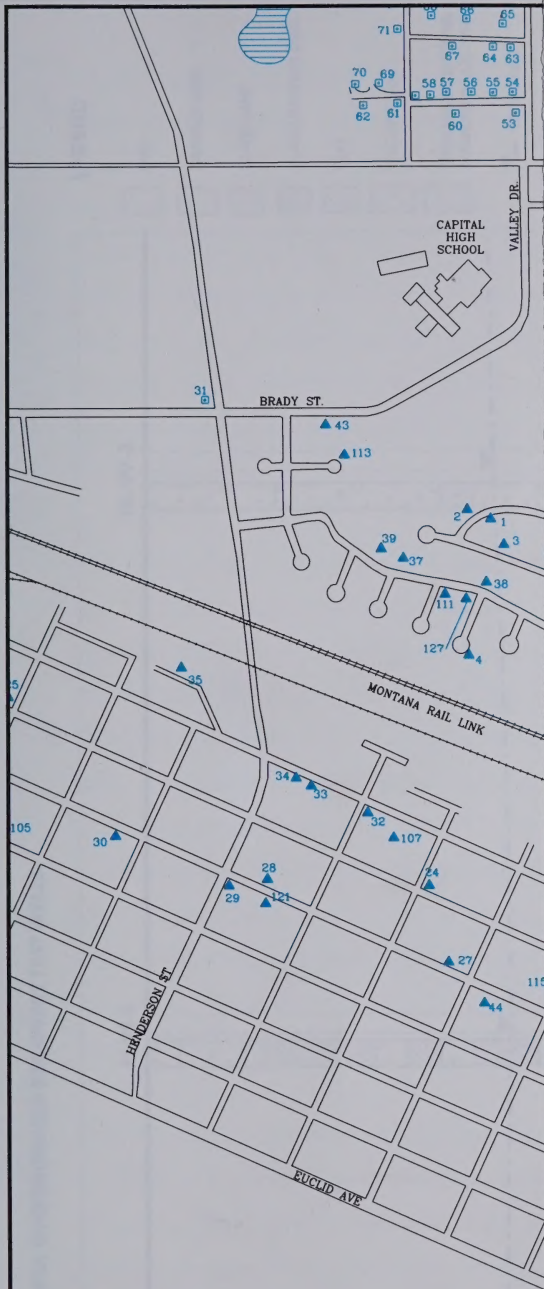
**STEADY-STATE
CAPTURE SCENARIO**

**FIGURE
2-2**

wells, short-term pumping tests (3-4 hours) on these wells and water quality sampling for volatile organic compounds (VOCs). The field procedures and findings for each of these tasks are described in the following sections. The wells were installed in the approximate location of the three western wells used by the model and their purpose was to evaluate the ability of the aquifer to produce sufficient yield required for effective capture of landfill constituents in this area. Additionally, the fourth well introduced the possibility of pulling additional contaminants into the eastern flow path. Wells located to the east of the golf course did not show evidence of landfill contamination. Installing and pumping a well in this region would pull water in this direction and could actually spread the contamination. For these reasons, the initial phase of testing focused on the western portion of the site.

2.5.2.2 Well Installation

The approximate locations for the proposed recovery wells were determined from the hydrologic modeling analysis and finalized in the field based on utility and access constraints. The locations of the installed wells, designated HL-99-1, HL-99-2 & HL-99-3, are shown in Figure 2-3. H&L Drilling of Helena, Montana drilled the wells using a forward rotary drill rig with a top drive-casing hammer. A Hydrometrics' hydrogeologist and licensed monitoring well constructor was present during drilling to log the geology and finalize well completion intervals. The boreholes were initially advanced to the total depth at each location to collect information on stratigraphy, water yield and specific conductivity (SC) of the groundwater with depth. SC is a general measure of the number of ions in solution and was used to detect general changes in groundwater quality with depth. Hydrometrics consulted with MDEQ representatives prior to finalizing the well completion depths and screened intervals. The wells were initially developed with air injection for approximately 30 minutes until the turbidity in the water cleared. The wells yielded approximately 40 gpm in well HL-99-1 and HL-99-3 and 30 gpm in well HL-99-2. Figure 2-4 shows the geology, static water levels and the well completion intervals for all three wells. Well completion details are shown on the wells logs and well completion diagrams in Appendix A.



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LEGEND

- L-1 ■ PIEZOMETER
- 3-6 ● MONITORING WELL
- 1-6 ▲ IRRIGATION WELL
- 80 □ DOMESTIC WELL
- 2 ● EXTRACTION WELL
- 115 ▨ INFILTRATION GALLERY (GROUNDWATER COLLECTION SYSTEM)
- 116 S STORM WATER OUTFALL FOR LAST CHANCE GULCH

LOCATION OF GROUNDWATER
EXTRACTION WELLS

FIGURE

2-3





SCALE
(in Feet) 800

LEGEND

- HL-1 ■ PIEZOMETER
- 83-6 ● MONITORING WELL
- 1-6 ▲ IRRIGATION WELL
- 80 □ DOMESTIC WELL
- HL-99-2 ● EXTRACTION WELL
- INFILTRATION GALLERY (GROUNDWATER COLLECTION SYSTEM)
- ⤵ STORM WATER OUTFALL FOR LAST CHANCE GULCH

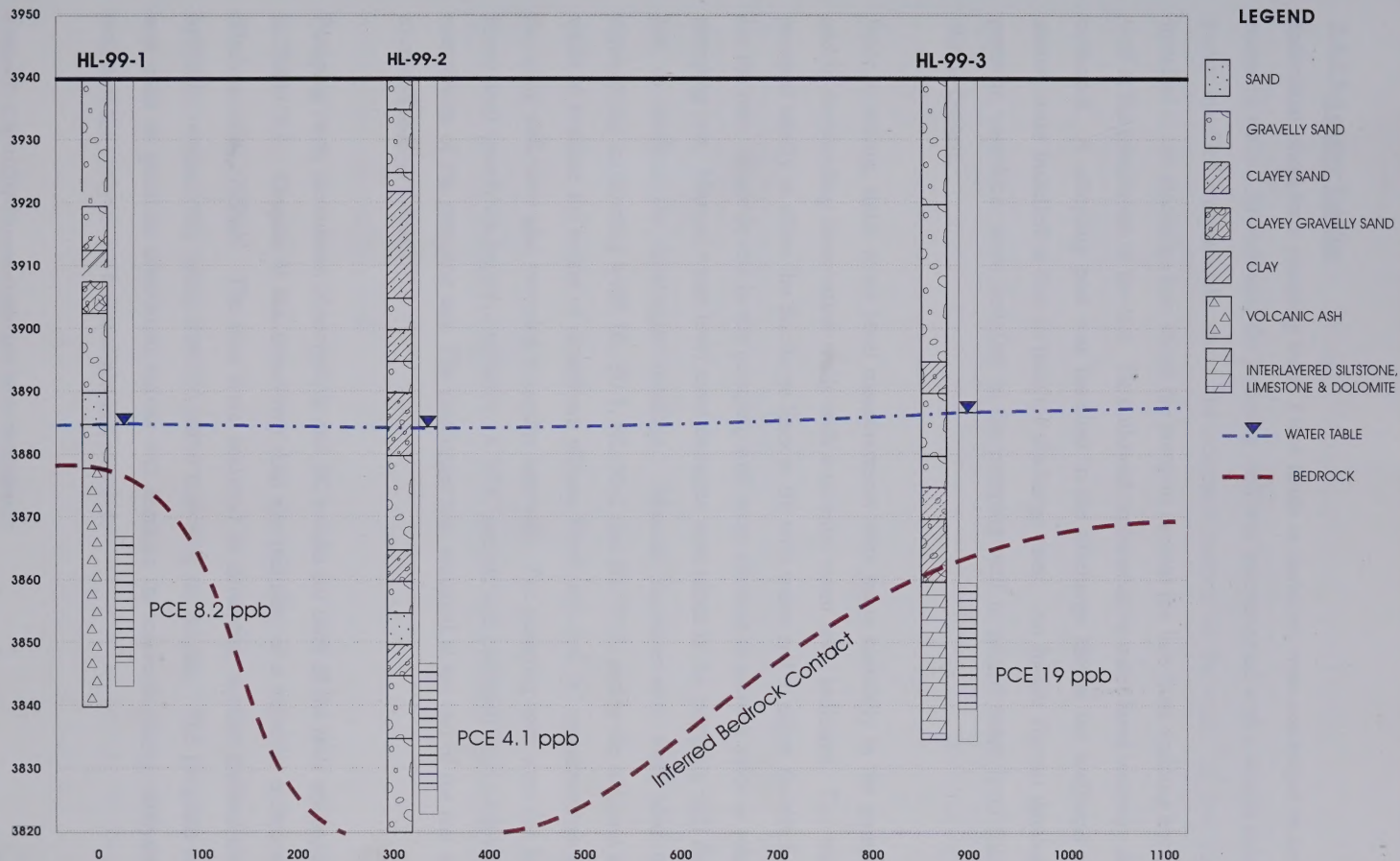
TWO-YEAR EVALUATION OF
GROUNDWATER EXTRACTION SYSTEM
AT THE HELENA LANDFILL
HELENA, MONTANA

LOCATION OF GROUNDWATER
EXTRACTION WELLS

FIGURE

2-3

HELENA LANDFILL GROUNDWATER RECOVERY TEST WELLS



Note: Reported PCE concentrations are from sampling on 6/28/99.

**TWO-YEAR EVALUATION OF
GROUNDWATER EXTRACTION SYSTEM
AT THE HELENA LANDFILL
HELENA, MONTANA**

**CROSS SECTION SHOWING
SITE STRATIGRAPHY AND
WELL COMPLETION DATA**

FIGURE

2-4

2.5.2.3 Aquifer Testing

Individual, short-term pumping tests, 3 to 4 hours in duration, were conducted at each of the recovery wells. At each site, the pumping well was instrumented with a 4-inch submersible pump installed immediately above the screened interval of the well. A foot valve was installed in the discharge line above the pump to prevent the line from draining back into the well at the conclusion of the test. This allowed representative water level recovery data to be collected. A sampling port was installed in the discharge line at the wellhead and flow meters were installed in-line to monitor discharge rates. An In-situ Hermit datalogger and pressure transducer were installed in the pumping well to record water level fluctuations during the test.

Prior to testing, static water level measurements were taken manually in the pumping well and in surrounding observation wells with a solonist water level indicator. The wells were pumped briefly to allow the discharge lines to fill with water and to adjust the discharge rate for the test. Water levels in the pumping well were allowed to recover prior to starting the pumping test. Manual water level measurements were taken in the pumping well during the test to confirm the datalogger readings. Manual measurements were also taken in surrounding monitoring wells HL-90-1, HL-90-2 and HL-90-3, and in the adjacent recovery wells to evaluate the extent of drawdown effects. Flow rates and SC measurements from the pumping well were also recorded at regular intervals. The pumping tests were run for 3 to 4 hours until drawdown began to stabilize. A VOC sample was collected from each well at the completion of the pumping test. The datalogger was restarted at the end of the test and used to record recovery data.

Pumping rates, drawdown observations and SC results for each of the tests are summarized in Table 2-1. Graphs of the drawdown data are included in a separate technical report (Hydrometrics, 1999a). The data were analyzed to determine aquifer transmissivity and hydraulic conductivity using standard curve matching techniques. The program Aqtesolv was used to generate drawdown curves and conduct the curve-matching analyses. The results of the analyses are summarized in Table 2-1.

TABLE 2-1. SUMMARY OF AQUIFER TEST RESULTS

PARAMETER	PUMPING WELL		
	HL-99-1	HL-99-2	HL-99-3
Measured Data			
Average Discharge (gpm)	23	28	28
Test Duration (min)	196	248	188
Maximum Drawdown in Pumping Well (feet)	6.13	18.62	8.17
Specific Conductance of groundwater at Completion of test ($\mu\text{mhos/cm}$)	950	899	841
Maximum Drawdown in Observation Wells (feet)			
HL-99-1	--	0.14	0.03
HL-99-2	0.05	--	0.16
HL-99-3	-0.06	0.11	--
HL-90-1	0.00	0.04	0.00
HL-90-2	0.00	0.03	0.05
HL-90-3	0.03	0.00	0.00
Calculated Data			
Approximate Saturated Thickness (ft)	40	60	50
Specific Capacity (gpm/ft)	3.8	1.5	3.4
Transmissivity (ft^2/day)			
Theis	196	108	258
Cooper Jacob	174	87	242
Neuman	154	122	264
Theis Recovery	145	75	208
Average Transmissivity (ft^2/day)	167	98	243
Average Hydraulic Conductivity (ft/day)	4.2	1.6	4.9

2.5.2.4 Groundwater Sampling

Two sets of groundwater samples were collected from all three extraction wells. The first set, collected on June 28, 1999, was collected after all the wells had been completed and developed, but prior to aquifer testing. The second set, collected July 8-12, 1999, were collected from the sample port located at the wellhead at the conclusion of each pumping test but prior to the well recovery analysis. These samples were collected to evaluate the water quality that would be encountered with long-term pumping to provide information to

determine discharge treatment options in the final detailed design. Sampling methodology is detailed in Section 3.3 of the technical report (Hydrometrics, 1999a).

The results of the June 28 sampling showed PCE at concentrations of 8.2 mg/L, 4.1 mg/L and 19 mg/L, in wells HL-99-1, HL-99-2, and HL-99-3 respectively. The results of the July 8-12 sampling showed PCE at concentrations of 7.8 mg/L, 5.8 mg/L and 24 mg/L, in wells HL-99-1, HL-99-2, and HL-99-3 respectively. Concentrations of several other typical landfill contaminants (dichlorofluoromethane, 1,1-dichloroethane, cis-1,2-dichloroethene, etc.) were also recorded, all at level less than the MCLs. These results were consistent with concentrations of similar compounds previously detected in nearby monitoring well HL-90-1.

2.5.2.5 Comparison with Hydrologic Model

The findings from the field investigation were generally consistent with the initial capture zone analysis with a few exceptions:

- Bedrock was encountered at shallower depths than anticipated at HL-99-1 and HL-99-3. Based on water level and water quality data, the upper portion of the bedrock aquifer at both of these wells is in indirect communication with the alluvial groundwater system and contains similar levels of landfill constituents. A groundwater extraction alternative is still potentially feasible with the observed site conditions.
- Aquifer permeability is somewhat lower than the initial assumptions used to evaluate this alternative. The field data indicate that hydraulic conductivities range from approximately 2 to 5 feet/day in the vicinity of the recovery wells versus 10 to 20 feet/day used in the initial modeling analysis.

Additional calculations were performed to evaluate whether this decrease in permeability would significantly alter the potential capture effectiveness of the recovery wells. The capture zones were calculated using an analytical groundwater flow model based on the average hydraulic conductivity from the field investigation. The results indicated an increase

in drawdown compared to the original capture scenario. As a result, the capture area is expanded, with the majority of flow from the landfill captured by HL-99-3 and HL-99-2.

The water levels, geology, and VOC concentrations encountered in the field were consistent with the previous analysis and confirmed that constituents from the landfill travel northwest along a relatively narrow flow path. The geology, although more variable than originally assumed, is still suitable for a groundwater extraction alternative. The necessary yields predicted by the groundwater flow model (approximately 20 to 30 gallons per minute) were achieved at each of the recovery wells resulting in significant zones of capture. While the presence of a bedrock groundwater flow system makes it more difficult to accurately characterize the capture zone boundaries, the field observations during testing were generally consistent with the model predictions.

2.5.2.6 Conclusions

Based on the results of the field investigation and computer modeling of the groundwater system, it appeared that groundwater extraction was a viable option for groundwater remediation at the Helena Landfill. The results of this investigation indicated that the three wells installed were sufficient to proceed with extended operational testing. Monitoring data from the next phase of work would establish whether these wells could effectively decrease downgradient levels of PCE below the MCL, or whether additional wells, including the one pumping well to the east used in the computer model, would be necessary. Concentrations of VOCs in the pumping wells were sufficiently low (an average of 12.6 mg/L at the flows pumped during aquifer testing) that simple single-stage aeration (i.e., spraying) prior to land application should provide adequate treatment to reduce concentrations below the MCL prior to discharge. However, monitoring would be conducted to confirm this. The results of this investigation indicated that modifying the Corrective Measures Assessment to incorporate a groundwater extraction alternative as a preferred corrective action was appropriate. Detailed design of the system was begun immediately to facilitate installation of the system before the start of the year 2000 irrigation season.

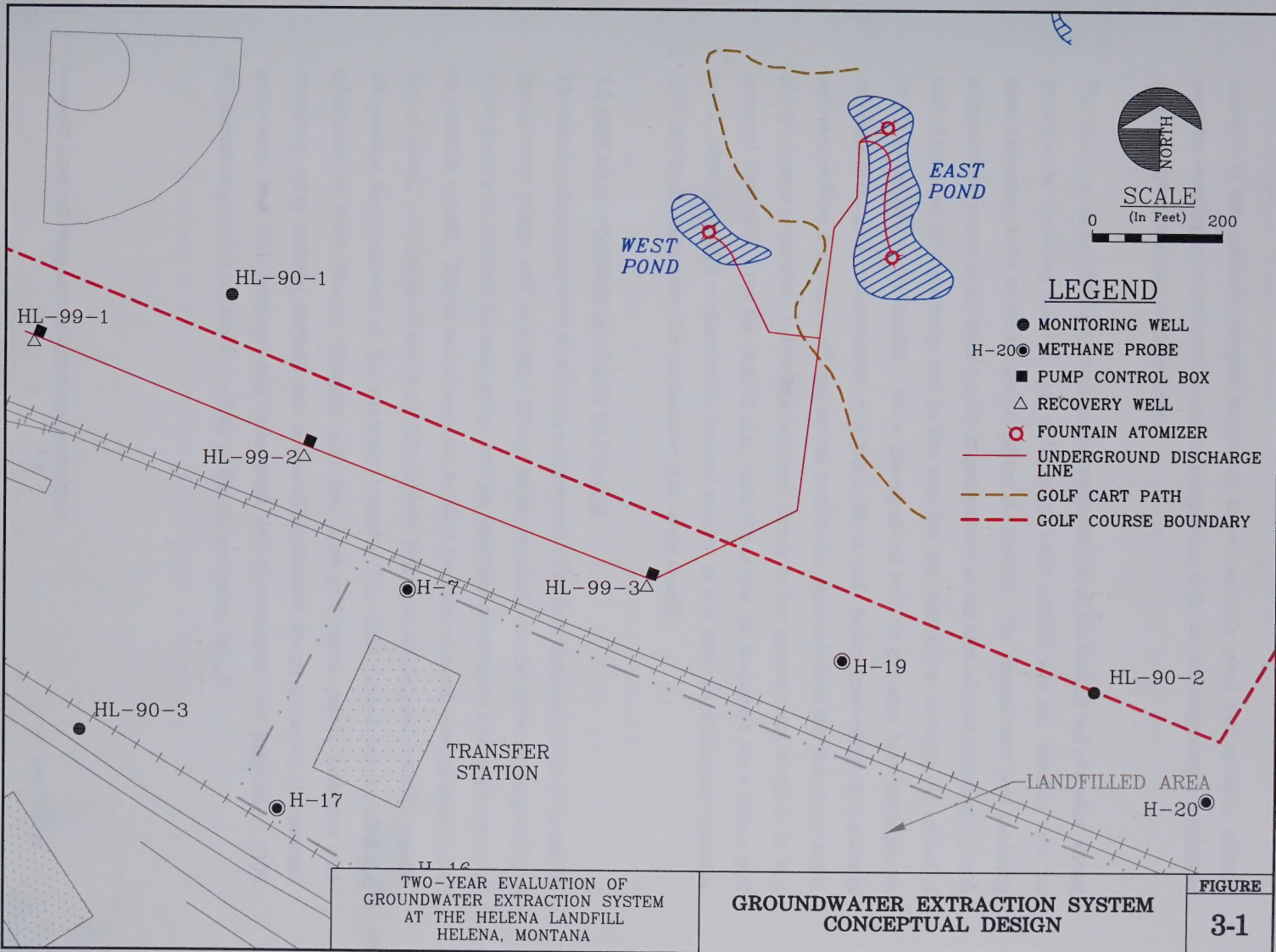
3.0 DESIGN AND CONSTRUCTION

3.1 CONCEPTUAL DESIGN

Figure 3-1 shows the conceptual design for the groundwater extraction/irrigation system proposed in the second addendum to the CMA (Hydrometrics, 1999b). The three wells already installed north of the landfill as part of the pilot study (HL-99-1, HL-99-2, and HL-99-3) would be equipped with pumps to capture groundwater and pump the water to the surface for treatment. Each well would also have a locking pump box with electrical control panel. Discharge lines from each pump would be manifolded into a single discharge line that would be installed underground and routed into existing PVC-lined irrigation ponds at the Bill Roberts Golf Course. PCE and other volatile organics are volatilized by pump aeration and by pumping the water through atomizing spray nozzles into the lined irrigation ponds. The pond water is a mix of capture well water and golf course well water. The pond water is then pumped through the golf course sprinkler system where further aeration and volatilization occurs. After deposition on the golf course, the treated water is either evapotranspired by the grass or re-infiltrated back into the groundwater system. The capture wells would be pumped during the golf course irrigation season (April through September) at the rates that were established in the pumping tests.

Wells HL-99-1, HL-99-2 and HL-99-3 would be pumped seasonally for a period of two years during which these wells, along with monitoring wells HL-90-1 and MPC-1, would be sampled on a quarterly basis. At the end of this testing period, the effectiveness of the system would be evaluated. The need for additional corrective action would also be evaluated at this time. The current semiannual and quarterly sampling regimes already in place would be maintained during this two-year period.

Concentrations of PCE in groundwater under the golf course are below the laboratory detection limit of 1.0 ppb in several areas. Additionally, the irrigation ponds are used to irrigate the entire golf course and cannot be directed to specific areas only. Therefore, environmental regulations stipulate that the applied treated water must meet non-degradation requirements (0.0005 ppb) at the point of application or where it touches the ground. In



addition to the quarterly samples mentioned above, monthly pond and sprinkler effluent samples would also be collected to ensure compliance with the non-degradation regulations and to monitor treatment effectiveness.

The fourth extraction well proposed for the northeast side of the landfill and evaluated during groundwater modeling (located east of the stormwater outfall) was not installed with the three extraction wells on the northwest side of the landfill. The groundwater flow modeling suggested the potential for water quality improvements in this area without operating a fourth well. Operation of a recovery well in this area has the potential to increase the spread of VOCs to the east of the landfill. Since downgradient wells in this area have never shown evidence of landfill contamination; it is preferable to wait before proceeding with a fourth recovery well in this area until operational results are obtained from the first three wells. However, as a precaution, a downgradient well shown by the groundwater model to be in a potential flow path from the landfill (i.e., well 90) would be monitored on a semiannual basis. Should landfill contamination become evident in this well, an additional extraction well may be installed along the northeastern side of the landfill.

3.2 DETAILED DESIGN AND BID PACKAGE

The detailed design included three main components. The first consisted of the submersible groundwater pumps and associated fittings to be installed into the three existing wells, a valve vault with controls for each pump, and the electrical connections required to produce an operable system. The second component entailed the excavation of approximately 2,000 feet of trench, installation of the black polyethylene pipe with bedding and backfill, and the compaction and gradation of the excavated trench. The final component included the installation of three floating fountains into two lined golf course ponds, complete with atomizing spray nozzles, anchors and hoses. The detailed design including the contract documents and bid package was completed by Hydrometrics in September 1999 (Hydrometrics, 1999c) and labeled as City of Helena project no. 99-15.

3.3 CONSTRUCTION AND START-UP

Construction began in October 1999 and was completed in May 2000. On June 12, 2000 the system began operation and the initial performance of the groundwater extraction system was evaluated.

3.3.1 System Start-Up

The pumps in the three extraction wells were all turned on the morning of June 12, 2000. Initial flow rates for each well ranged from 42 to 50 gpm according to the flow meters present in each of the well control boxes. These flows dropped back to approximately 35 gpm with all three wells pumping simultaneously. The flows were throttled back to approximately 25 gpm (necessary flowrate determined during groundwater modeling) in each well using the ball valve located in each of the control boxes. The system was monitored for several hours to check for leaks and other problems and to monitor water levels in the extraction wells.

3.3.2 Sampling

Water sampling was conducted each afternoon from June 12 through June 19 (except for Saturday, June 17, and Sunday, June 18). Samples were collected from each wellhead, the east pond surface, the east pond at depth, and from the north atomizing spray nozzle in the east pond. At each wellhead, the flow was recorded and a sample was collected from the hose bib. At the pond, a boat was used to collect a sample from the pond surface near the center of the pond. A peristaltic pump was then used to collect a sample from near the bottom of the pond. Finally, a stainless steel bowl was used to collect nozzle spray just before it hit the pond. On June 16, a sample was also collected from the irrigation system using the steel bowl to catch the sprinkler water before it reached the ground. All samples were collected in 40 mL glass vials with no headspace, preserved with hydrochloric acid, and refrigerated prior to analysis. Split samples were collected on June 19 at the pond surface, pond bottom, and spray nozzle and sent to Energy Labs for analysis. Table 3-1 includes the flow rates, weather conditions, and samples collected during the sampling period.

TABLE 3-1. SAMPLING SCHEDULE AND CONDITIONS

DATE	June 12	June 14	June 15	June 16	June 19
Sample Location					
Well HL-99-1	X	X	X	X	X
Well HL-99-2	X	X	X	X	X
Well HL-99-3	X	X	X	X	X
Pond Surface	X	X	X	X	X ¹
Pond Bottom	X	X	X	X	X ¹
Pond Spray Nozzle	X	X	X	X	X ¹
Golf Course Sprinklers				X	
Flows (gpm)					
HL-99-1	22	22	22	22	21
HL-99-2	25	27	25	26	26
HL-99-3	25	25	25	26	24
Weather					
	lt. Rain, windy, 60 F	Cloudy, windy, 75 F	lt. rain, breeze, 75 F	cloudy, breeze, 70 F	cloudy, windy, 85 F

¹ Split Sample was sent to lab for confirmation.

3.3.3 Sample Analysis

To allow for more sample analyses and timely results, Hydrometrics utilized an SRI Instruments Model 8260 gas chromatograph (GC) to field screen samples for the presence of tetrachloroethene (PCE), the contaminant of concern. The GC uses an automatic purge and trap collection system and PID and FID detectors. A computer interface controlled the GC and recorded PID and FID readings to produce complete chromatograms. Ultra-pure helium gas was used for both the purge and carrier gases while hydrogen gas was used to fuel the FID flame. The GC was calibrated with 5 ppb and 0.5 ppb standard PCE solutions. Although the analyses performed on the GC were used primarily for screening purposes, approximate concentrations were assigned based on the size of the peak compared to the size of the peaks obtained during calibration. Table 3-2 shows the results of these analyses. The split samples sent to Energy Labs showed results similar to those determined use the GC.

TABLE 3-2. RESULTS OF GC ANALYSES

Sample Site	PCE Concentrations (ppb)					
	June 12	June 14	June 15	June 16	June 19 – field result	June 19 – lab result
Well HL-99-1	3.0	2.8	Vial broke	2.7	3.0	No sample
Well HL-99-2	1.2	Vial broke	2.7	2.2	2.2	No sample
Well HL-99-3	14.2	10.1	8.2	7.0	6.7	No sample
Pond Surface	ND	0.6	ND	ND	ND	ND
Pond Bottom	ND	ND	ND	ND	ND	ND
Pond Spray Nozzle	0.6	ND	0.4(J)	0.3(J)	0.3(J)	0.96(J)
Golf Course Sprinkler	No sample	No sample	No sample	ND	No sample	No sample

- “ND” indicates that PCE was not detected: any concentrations of PCE present were below the detection limit of the GC being used. (J) values indicate that PCE was present, but below the Limit of Quantitation of 1.0 ppb.

3.3.4 Conclusions

During the initial start-up phase, the system operated as designed. The pumps were able to maintain the flows estimated necessary during modeling and the atomizing spray nozzles used for primary treatment appeared to be volatilizing the majority of the PCE. The residual PCE was removed in the pond and/or the sprinkler system. There was no evidence that the system was land-applying water with concentrations of PCE above the required reporting limit of 0.5 ppb, as required by MDEQ.

For the next two years, as required by MDEQ, the City collected VOC samples of the pond surface water and sprinkler effluent on a monthly basis during system operation. In addition, the extraction wells and compliance wells were sampled again as part of the quarterly sampling events in March and September to monitor any effects the extraction system may have had on downgradient water quality. After a two-year monitoring period, the City was to evaluate the effectiveness of the system in reducing concentrations of PCE in the compliance wells and determine whether additional corrective measures would be necessary.

4.2 SURFACE WATER MONITORING

A surface water sample from the edge of the east pond and a pond sample of the sprinkler effluent were collected monthly during system operation. The samples were sent to Enviro Laboratory for VOC analysis using the maximum detection limit of 0.5 ppb, the maximum level allowed by MDEQ to be land applied on the golf course. Concentrations of all PCE surfactants in both the pond and the sprinkler system were below the laboratory reporting limit of 0.5 ppb.

4.3 GROUND WATER MONITORING

Groundwater samples were collected from each of the extraction wells and from compliance wells HL-99-1 and MFC-1 on a quarterly basis. The samples were collected according to the approved sampling and analysis plan (Hydroscience, 1994). The samples were sent to

4.0 TWO-YEAR EVALUATION

The two-year evaluation period for the groundwater extraction system ended in June 2002. On June 18, a meeting was held with John Rundquist of the City, Pat Crowley with MDEQ and Hydrometrics' personnel to discuss the system operations and remediation effectiveness as well as the potential to maximize groundwater recovery and consequently accelerate the remediation process. In addition, a capture zone analysis was performed in May 2002 to provide a better understanding of the operation of the system and to aid in making recommendations to optimize the performance of the system.

4.1 OPERATING CONDITIONS

During the two-year evaluation period, the system operated from June 12, 2000 through October 2000, from April 2001 through October 2001, and from April 2002 through September 2002. The system operated almost continuously during the operating season with only a few days downtime for minor repairs, etc. The system was operated at design capacity using the flowrates determined during the initial pump tests (25 gpm for HL-99-1, and 35 gpm each for HL-99-2 and HL-99-3). Minor maintenance included cleaning the rotometers and atomizing spray nozzles.

4.2 SURFACE WATER MONITORING

A surface water sample from the edge of the east pond and a pan sample of the sprinkler effluent were collected monthly during system operation. The samples were sent to Energy Laboratories for VOC analysis using the minimum detection limit of 0.5 ppb, the maximum level allowed by MDEQ to be land applied on the golf course. Concentrations of all PCE samples in both the pond and the sprinkler system were below the laboratory reporting limit of 0.5 ppb.

4.3 GROUNDWATER MONITORING

Groundwater samples were collected from each of the extraction wells and from compliance wells HL-90-1 and MPC-1 on a quarterly basis. The samples were collected according to the approved sampling and analysis plan (Hydrometrics, 1994). The samples were sent to

Energy Laboratories for VOC analysis. All results were submitted to MDEQ. Figure 4-1 shows the PCE results from those sampling events as well as the periods of operation of the extraction system. Concentrations in the extraction wells show substantial fluctuations and have not yet shown any decreasing trends. Similarly, compliance well MPC-1 has not shown a decreasing trend and is still one to four parts per billion over the MCL of 5 ppb. It should be noted that this well is beyond the zone of influence of the extraction system and water quality improvements due to the extraction system were not expected in this area. Due to the shallow construction of well HL-90-1 and its proximity to the extraction system, it was only possible to collect samples during the wettest seasons after a substantial recovery period. However, the samples that were collected show a definite decrease in PCE levels in the past two years. Concentrations have decreased from an average of 15 ppb in 1999 to 6.2 ppb in 2002 or more than 50% in two years of operation. At this rate, well HL-90-1 may be in compliance within the next year. Each operating season, almost 25 million gallons of water is extracted and used as irrigation water on the Bill Roberts Golf Course. With an average concentration of 5 ppb, approximately three pounds of PCE have been extracted from the groundwater system to date.

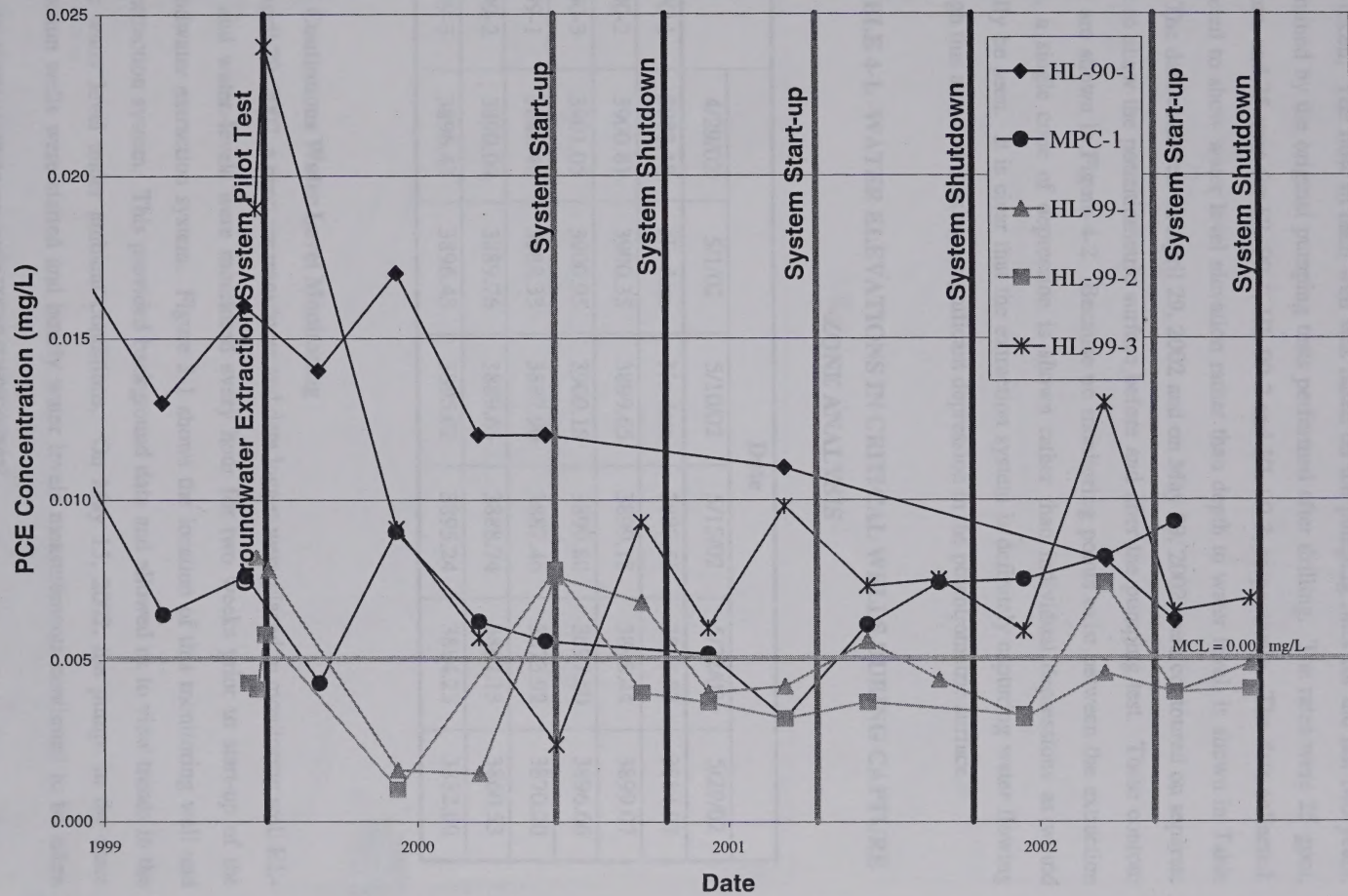
4.4 CAPTURE ZONE ANALYSIS

A capture zone analysis was performed in April and May of 2002 to better understand the operation of the system and to make recommendations to optimize the performance of the system. The capture zone analysis consisted of the collection of detailed water level data during initial system operation. This data was used to evaluate the zone of capture for the existing system and assess whether the system could be expanded through additional extraction wells or increased pumping rates to further facilitate capture of PCE.

4.4.1 Manual Water Level Monitoring

Beginning on April 29, 2002, two weeks prior to the start of the pumping test, and during the two-week pumping test, manual water level measurements were taken on a weekly basis in monitoring wells HL-90-1, HL-90-2 and HL-90-3 and in extraction wells HL-99-1, HL-99-2, and HL-99-3. The locations of these wells are shown on Figure 2-3. The pumps in the extraction wells were activated on May 15, 2002, after the weekly water level measurements

FIGURE 4-1. PCE RESULTS FOR GROUNDWATER EXTRACTION SYSTEM



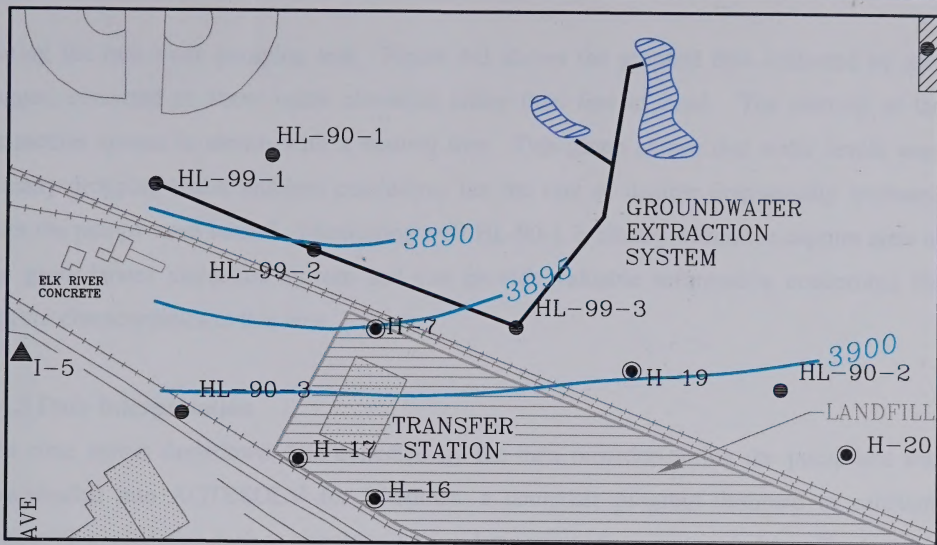
were taken. The flow in each well was based on the pumping rates for the last two years, determined by the original pumping tests performed after drilling. The rates were 25 gpm, 35 gpm, and 35 gpm for HL-99-1, HL-99-2 and HL-99-3, respectively. The data collected, corrected to show water level elevation rather than depth to water level, is shown in Table 4-1. The data collected on April 29, 2002 and on May 29, 2002 were contoured on separate maps to show the potentiometric surface before and after the pumping test. These contour maps are shown in Figure 4-2. Because no monitoring points exist between the extraction wells, a single cone of depression is shown rather than individual depressions as would actually be seen. It is clear that the extraction system is definitely capturing water flowing through this area and causing a significant depression in the potentiometric surface.

TABLE 4-1. WATER ELEVATIONS IN CRITICAL WELLS DURING CAPTURE ZONE ANALYSIS

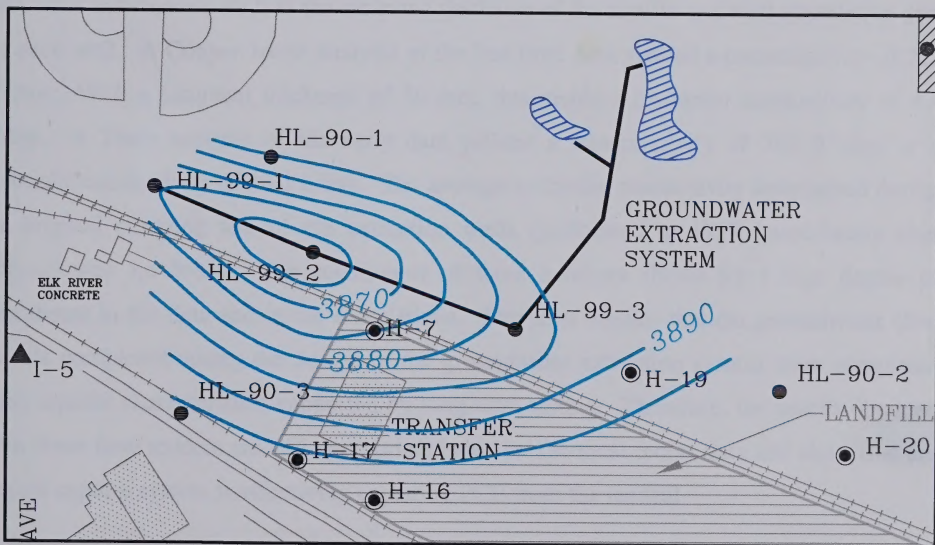
Well	Date					
	4/29/02	5/1/02	5/10/02	5/15/02	5/22/02	5/29/02
HL-90-1	3888.18	No data	No data	3887.55	3885.83	3884.97
HL-90-2	3900.81	3900.35	3899.65	3899.18	3898.44	3899.07
HL-90-3	3901.05	3900.95	3900.18	3899.80	3897.50	3896.66
HL-99-1	3888.46	3888.33	3887.90	3887.46	3873.92	3870.20
HL-99-2	3890.04	3889.76	3889.65	3888.74	3862.13	3860.53
HL-99-3	3896.43	3896.43	3895.62	3895.24	3884.23	3882.60

4.4.2 Continuous Water Level Monitoring

On April 29, 2002, a pressure transducer and data logger were placed in monitoring well HL-90-1 and water levels were monitored every hour for two weeks prior to start-up of the groundwater extraction system. Figure 3-1 shows the location of this monitoring well and the extraction system. This provided background data and allowed us to view trends in the static water level under ambient conditions. On May 15, 2002, the pumps in the three extraction wells were started and hourly water levels measurements continued to be taken



APRIL 29, 2002



MAY 29, 2002



SCALE

0 (In Feet) 400

TWO-YEAR EVALUATION OF
GROUNDWATER EXTRACTION SYSTEM
AT THE HELENA LANDFILL
HELENA, MONTANA

POTENTIOMETRIC SURFACES
BEFORE AND AFTER
CAPTURE ZONE ANALYSIS
PUMPING TEST

FIGURE

4-2

during the two-week pumping test. Figure 4-3 shows the graphed data collected by data logger, corrected to show water elevation rather than feet of head. The start-up of the extraction system is shown with a vertical line. This graph shows that water levels were already dropping under ambient conditions, but the rate of decline dramatically increased after the pumps were started. Monitoring well HL-90-1 is clearly within the capture zone of the groundwater extraction system and can provide valuable information concerning the aquifer characteristics in this area.

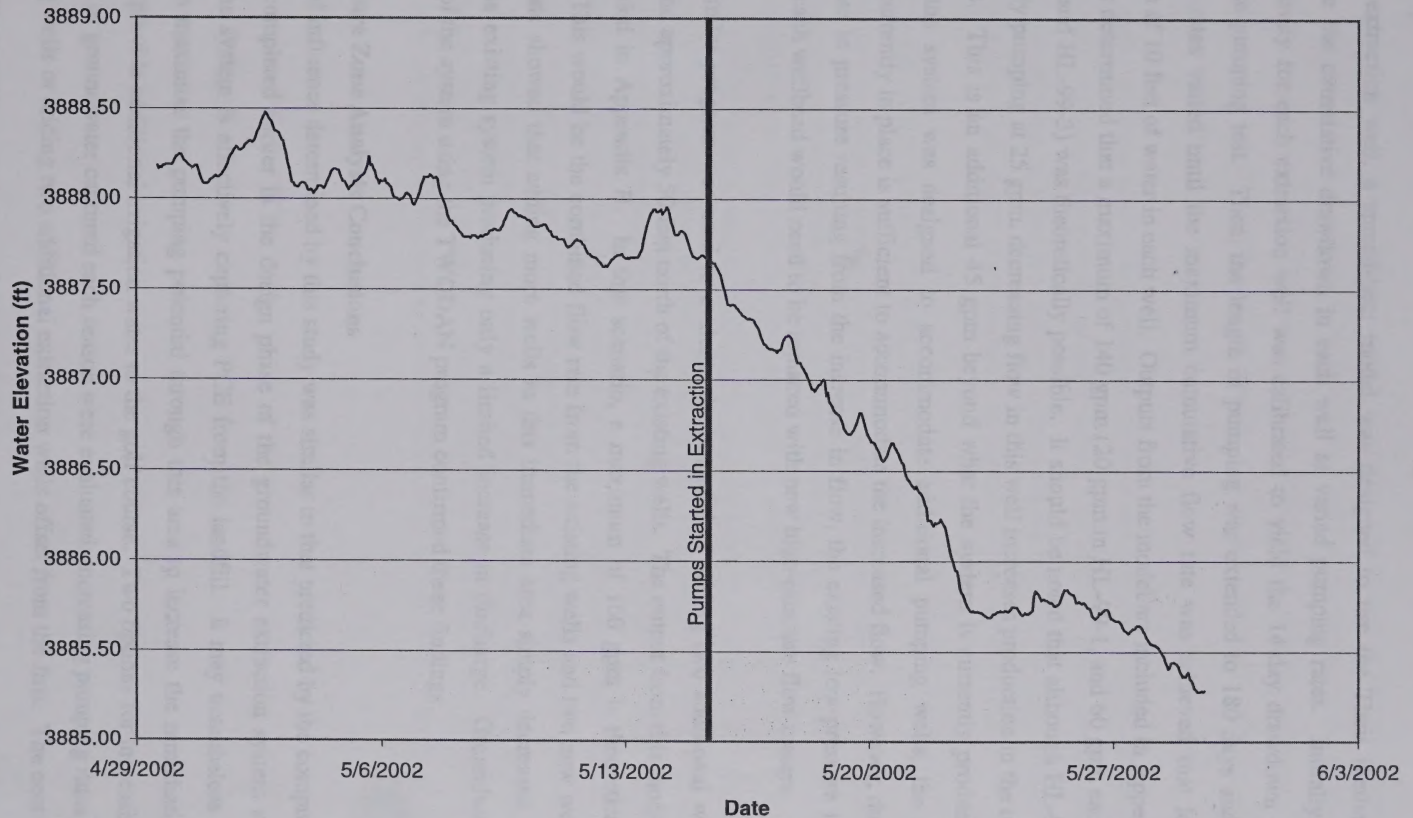
4.4.3 Data Interpretation

The time versus drawdown data collected by the data recorder during the pump test was downloaded into AQTESOLV for Windows, a computer program designed to calculate aquifer characteristics such as transmissivity and storativity from just such data. The location and pumping rates of each of the pumping wells were also entered into the program along with other information such as the saturated thickness of the aquifer and well completion data for each well. A Cooper-Jacob analysis of the late-time data yielded a transmissivity of 222 ft²/day. With a saturated thickness of 50 feet, this yields a hydraulic conductivity of 4.4 ft/day. A Theis analysis of the early data yielded a transmissivity of 780 ft²/day, or a hydraulic conductivity of 15.6 ft/day. The average hydraulic conductivity determined during the original pumping test of the extraction wells (performed in 1999 immediately after drilling) was 3.6 ft/day. The consistency of these numbers allows for a high degree of confidence in the data and in the calculations. This also implies that the groundwater flow models completed during the design of the groundwater extraction system were completed using aquifer characteristics supported by long-term testing. Therefore, the results obtained from these flow models are still appropriate based on the most recent data and show that the present capture system is effectively capturing PCE from the landfill.

4.4.4 Evaluation of Maximum Pumping Rates

Although the existing wells appear to be effective at capturing residual PCE from the landfill, water quality at well HL-90-1 has not yet met the goal of 5 ppb. Additional groundwater capture may be desirable to increase the rate of PCE removal as well as to provide even more irrigation water to the golf course. To evaluate the maximum potential pumping rates of each

**FIGURE 4-3. CONTINUOUS WATER LEVEL MONITORING AT HL-90-1
GROUNDWATER EXTRACTION SYSTEM CAPTURE ZONE ANALYSIS
AT THE CITY OF HELENA LANDFILL**



existing extraction well, a spreadsheet model was designed to use the Theis method to determine the cumulative drawdown in each well at varied pumping rates. Initially, the transmissivity for each extraction well was calibrated to yield the 14-day drawdown seen during the pumping test. Then, the length of pumping was extended to 180 days and the pumping rates varied until the maximum cumulative flow rate was achieved that left a minimum of 10 feet of water in each well. Outputs from the model are included in Appendix B. It was determined that a maximum of 140 gpm (20 gpm in HL-99-1, and 60 gpm each in HL-99-2 and HL-99-3) was theoretically possible. It should be noted that although HL-99-1 is currently pumping at 25 gpm, decreasing flow in this well increases production in the other two wells. This is an additional 45 gpm beyond what the system is currently producing. Because the system was designed to accommodate additional pumping wells, the line capacity currently in place is sufficient to accommodate the increased flow. However, due to the increase in pressure resulting from the increase in flow, the existing low-pressure flow meters at each wellhead would need to be replaced with new high-pressure flow meters.

Next, a similar program was used to evaluate the potential of adding two additional wells between and approximately 50 feet north of the existing wells. The output from this model is also included in Appendix B. In this scenario, a maximum of 160 gpm is theoretically possible. This would be the combined flow rate from the existing wells and two new wells. The analysis showed that adding more wells in this immediate area simply decreased the yield of the existing system producing only a limited increase in discharge. Groundwater modeling of the system using the TWODAN program confirmed these findings.

4.4.5 Capture Zone Analysis Conclusions

The zone of influence determined by this study was similar to that predicted by the computer modeling completed earlier in the design phase of the groundwater extraction system and indicates the system is effectively capturing PCE from the landfill. It may nonetheless be desirable to maximize the pumping potential through this area to increase the remediation rate and to provide additional irrigation water to the golf course. Two options for increasing the amount of groundwater captured each season were evaluated: increasing pumping rates in the existing wells or adding two additional extraction wells offset from the first. The cost of

each option was also evaluated. Based on price per gallon per minute of increased system capacity, maximizing the pumping rates in the existing wells was selected as the preferred alternative (\$222/gpm versus \$1538/gpm). As with the existing system, increasing the capacity will provide the City with additional water for the golf course, thereby repaying installation costs over time.

New flow meters were installed in September of this year and flow rates will be maximized in the extraction wells during the 2003 operating season. In addition, time-operated clocks were added to each pump to allow us to monitor if the pumping rates are too high, forcing the pumps to cycle on and off, which is not desirable for capture system effectiveness.

4.5 TWO-YEAR EVALUATION CONCLUSIONS

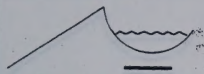
The groundwater extraction system is effectively capturing contaminants leaving the landfill and improving downgradient water quality. Concentrations of PCE in compliance well HL-90-1 have dropped more than 50% in two years from an average of 15 ppm in 1999 to 6.2 ppm in June of 2002. At this rate, this well may be in compliance by the end of the operating season 2003. It may nonetheless be desirable to maximize the pumping potential through this area to increase the remediation rate and to provide additional irrigation water to the golf course. Therefore, the extraction wells were plumbed with high-pressure flow meters and flows in these wells will be maximized while maintaining ten feet of water head in the wells. Due to the potential to spread contamination northeast of the landfill, additional extraction wells will not be added in this area at this time. Groundwater will continue to be monitored according to the existing monitoring schedule to evaluate additional changes in water quality.

5.0 REFERENCES

- Hydrometrics, 1991. Hydrogeological Investigation of the City of Helena Landfill.
- Hydrometrics, 1993. Helena Landfill Closure Plan.
- Hydrometrics, 1994. Helena Landfill Sampling and Analysis Plan.
- Hydrometrics, 1995. Corrective Measures Assessment, City of Helena Landfill, Helena, Montana.
- Hydrometrics, 1996. Addendum to Corrective Measures Assessment for the Helena Landfill, Helena, Montana.
- Hydrometrics, 1999a. Evaluation of Groundwater Extraction Remediation Alternative at the Helena Landfill, Helena, Montana.
- Hydrometrics, 1999b. Second Addendum to Corrective Measure Assessment for the Helena Landfill, Helena, Montana.
- Hydrometrics, 1999c. Contract Documents and Specifications for Helena Landfill Groundwater Extraction System.

APPENDIX A

WELL LOGS AND COMPLETION DIAGRAMS FOR EXTRACTION WELLS



HYDROMETRICS INC.

Consulting Scientists and Engineers
Helena, Montana

Recovery Well

Hole Name: HL-99-1

Date Hole Started: 6/17/99 Date Hole Finished: 6/24/99

Client: City of Helena

Project: Groundwater Remediation

County: Lewis and Clark State: Montana

Property Owner: City of Helena

Legal Description: SW,NW,SW Sec19, T10N, R3W

Descriptive Location: South of City of Helena
baseball fields

Recorded By: JR

Drilling Company: H&L Drilling

Driller: Mark Miller

Drilling Method: Air Rotary

Drilling Fluids Used: Water

Purpose of Hole: Install Recovery Well

Target Aquifer: Shallow Groundwater

Hole Diameter (in): 8

Total Depth Drilled (ft): 100

WELL COMPLETION	Y/N	DESCRIPTION	INTERVAL
Well Installed?	Y	8" steel to 40', 5" steel 0-75', screen 73-93', sump 93-98'	
Surface Casing Used?	N		
Screen/Perforations?	Y	0.020 slot stainless steel	73-93
Sand Pack?	Y	10-20 silica sand	70-100'
Annular Seal?	Y	Bentonite Chips	40-70'
Surface Seal?	N		
DEVELOPMENT/SAMPLING			
Well Developed?	Y	pumping at 40 gpm for 3 hours	
Water Samples Taken?	Y	volatile organics	
Boring Samples Taken?	N		

Static Water Level Below MP: 56.70

Date: 6/28/99

MP Description: top of steel casing

MP Height Above or Below Ground (ft): 1.57

Surface Casing Height (ft): 1.87

Riser Height (ft): 1.57

Ground Surface Elevation (ft): 3941.58

MP Elevation (ft): 3943.15

Remarks: N 506507.136 E 506741.293

Northing and Easting are based on City of Helena coordinate positions which are based on Mount Helena having coordinates N500000, E500000

WELL CONSTRUCTION

0.08-inch steel casing to
41 feet, 5-inch steel
casing to 100 feet



73.0
0.020 Slot Screen

93.0
5-inch steel casing for
sump

68.0
J-Packer
70.0
10/20 Silica Sand

Bottom of Hole 100.0

GRAPHICS

GEOLOGICAL DESCRIPTION

0.0 - 18.0' Gravel Fill

Sand and Gravel, grey, fine to coarse sand, fine to medium gravel, unconsolidated, dry.

18.0 - 25.0' Gravelly Sand

black, green, red, medium to coarse grain, 1/4 to 1/2 inch size gravel, start adding water for drilling.

25.0 - 30.0' Clayey Gravelly Sand

medium coarse sand as above, fine subrounded gravel, 20% brownish tan clay.

30.0 - 35.0' Clayey Sandy Gravel

dark black, fine to medium size (1/2 to 1.0 -inch) gravel, abundant coarse sand, predominantly diorite composition.

35.0 - 50.0' Gravelly Sand

multicolored, green, black, dark red, coarse grain, angular, trace clayey, abundant argillite, limestone, chert and dark igneous fragments, borehole not making any water.

50.0 - 55.0' Sand

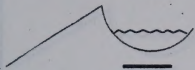
black, dark green, coarse grain, angular, predominantly diorite (?) composition, iron stained, borehole not yielding water.

55.0 - 62.0' Gravelly Sand

sand as above, 5% fine gravel, 15% light tan igneous tuff, borehole making less than 1 gpm.

62.0 - 100.0' Volcanic Tuff

light tan, siliceous, numerous angular rock inclusions, borehole making 5 gpm at 70 feet, 10 gpm at 80 feet, and 12 gpm at 100 feet.



Well Construction Diagram

Geological Description

0.0 8-inch steel casing to
41 feet, 5-inch steel
casing to 100 feet



73.0
0.020 Slot Screen

93.0
5-inch steel casing for
sump

68.0
J-Packer
70.0
10/20 Silica Sand

Bottom of Hole 100.0

0.0 - 18.0'

Gravel Fill

Sand and Gravel, grey, fine to coarse sand, fine to medium gravel, unconsolidated, dry.

18.0 - 25.0'

Gravelly Sand

black, green, red, medium to coarse grain, 1/4 to 1/2 inch size gravel, start adding water for drilling.

25.0 - 30.0'

Clayey Gravelly Sand

medium coarse sand as above, fine subrounded gravel, 20% brownish tan clay.

30.0 - 35.0'

Clayey Sandy Gravel

dark black, fine to medium size (1/2 to 1.0 -inch) gravel, abundant coarse sand, predominantly diorite composition.

35.0 - 50.0'

Gravelly Sand

multicolored, green, black, dark red, coarse grain, angular, trace clayey, abundant argillite, limestone, chert and dark igneous fragments, borehole not making any water.

50.0 - 55.0'

Sand

black, dark green, coarse grain, angular, predominantly diorite (?) composition, iron stained, borehole not yielding water.

55.0 - 62.0'

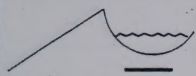
Gravelly Sand

sand as above, 5% fine gravel, 15% light tan igneous tuff, borehole making less than 1 gpm.

62.0 - 100.0'

Volcanic Tuff

light tan, siliceous, numerous angular rock inclusions, borehole making 5 gpm at 70 feet, 10 gpm at 80 feet, and 12 gpm at 100 feet.



HYDROMETRICS INC.

Consulting Scientists and Engineers
Helena, Montana

Recovery Well

Hole Name: HL-99-2

Date Hole Started: 6/16/99 Date Hole Finished: 6/16/99

Client: City of Helena

Project: Groundwater Remediation

County: Lewis and Clark State: Montana

Property Owner: City of Helena

Legal Description: SE,NW,SW Sec19, T10N, R3W

Descriptive Location: South of Golf Course
Driving Range

Recorded By: JR

Drilling Company: H&L Drilling

Driller: Mark Miller

Drilling Method: Air Rotary

Drilling Fluids Used: Water

Purpose of Hole: Install Recovery Well

Target Aquifer: Shallow Groundwater

Hole Diameter (in): 6

Total Depth Drilled (ft): 120

WELL COMPLETION	Y/N	DESCRIPTION	INTERVAL
-----------------	-----	-------------	----------

Well Installed?	Y	6" steel to 95', screen 93 to 113', sump 113-118'	
-----------------	---	---	--

Surface Casing Used?	N		
----------------------	---	--	--

Screen/Perforations?	Y	0.020 slot stainless steel	93-113
----------------------	---	----------------------------	--------

Sand Pack?	N		
------------	---	--	--

Annular Seal?	Y	Bentonite powder behind driven steel 0-95'	
---------------	---	--	--

Surface Seal?	N		
---------------	---	--	--

DEVELOPMENT/SAMPLING

Well Developed?	Y	pumping at 30 gpm for 4 hours	
-----------------	---	-------------------------------	--

Water Samples Taken?	Y	volatile organics	
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Boring Samples Taken?	N		
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Static Water Level Below MP: 57.75

Surface Casing Height (ft): 1.64

Date: 6/28/99

Riser Height (ft): 1.64

MP Description: top of steel casing

Ground Surface Elevation (ft): 3944.11

MP Height Above or Below Ground (ft): 1.64

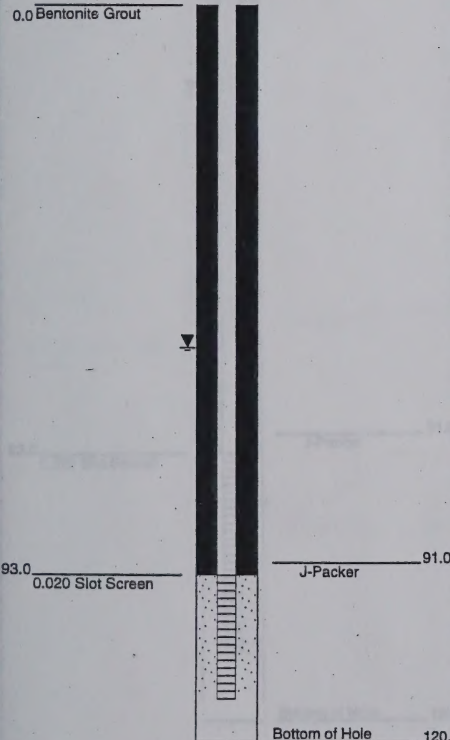
MP Elevation (ft): 3945.75

Remarks: N 506349.567 E 507807.083

Northing and Easting are based on City of Helena coordinate positions which are based on Mount Helena having coordinates N500000, E500000

WELL CONSTRUCTION

0.0 Bentonite Grout



GRAPHICS

GEOLOGICAL DESCRIPTION

0.0 - 5.0' **Gravelly Sand**
tan, light brown, fine to coarse grain, moderately rounded, poorly sorted, dry, 10% 1-inch gravel, unconsolidated.

5.0 - 15.0' **Gravelly Sand**
as above, primarily fine grain sand, moderately sorted, dry, unconsolidated.

15.0 - 18.0' **Sand**
as above, light brown, becoming clayey and slightly moist at 18 feet.

18.0 - 35.0' **Clayey Sand**
brown, black, white, coarse grain, moderately sorted, clayey, start adding water for drilling, trace fine gravel.

35.0 - 40.0' **Gravelly Sand**
brown, black, coarse grain, angular, moderately sorted, hard drilling, still dry, water levels in area wells are at 55 feet below ground surface.

40.0 - 45.0' **Clayey Sand**
multicolored, coarse grain, well sorted, clayey, hard drilling, borehole not yielding any water.

45.0 - 50.0' **Gravelly Sand**
as above, coarse grain, no clay, hard drilling, dry, gravel is 1-inch in size, moderately rounded.

50.0 - 60.0' **Gravelly Clayey Sand**
multicolored, coarse grain, angular, clayey, light brown clay.

60.0 - 75.0' **Gravelly Sand**
multicolored as above, coarse grain, 15-20% fine gravel, subangular to moderately rounded. Stop at 60 feet and let hole sit for 5 minutes to check for water. Borehole making less than 1/4 gpm.

75.0 - 80.0' **Gravelly Clayey Sand**
multicolored sand and gravel, coarse grain sand, angular, fine 1-inch size gravel, moderately rounded, clayey, clay is light tan and sticky.

80.0 - 85.0' **Gravelly Sand**
as above, no clay, borehole not making much water, driller adding approximately 5 gpm for drilling.

85.0 - 90.0' **Sand**
multicolored, red, green, black, coarse grain, trace fine gravel.

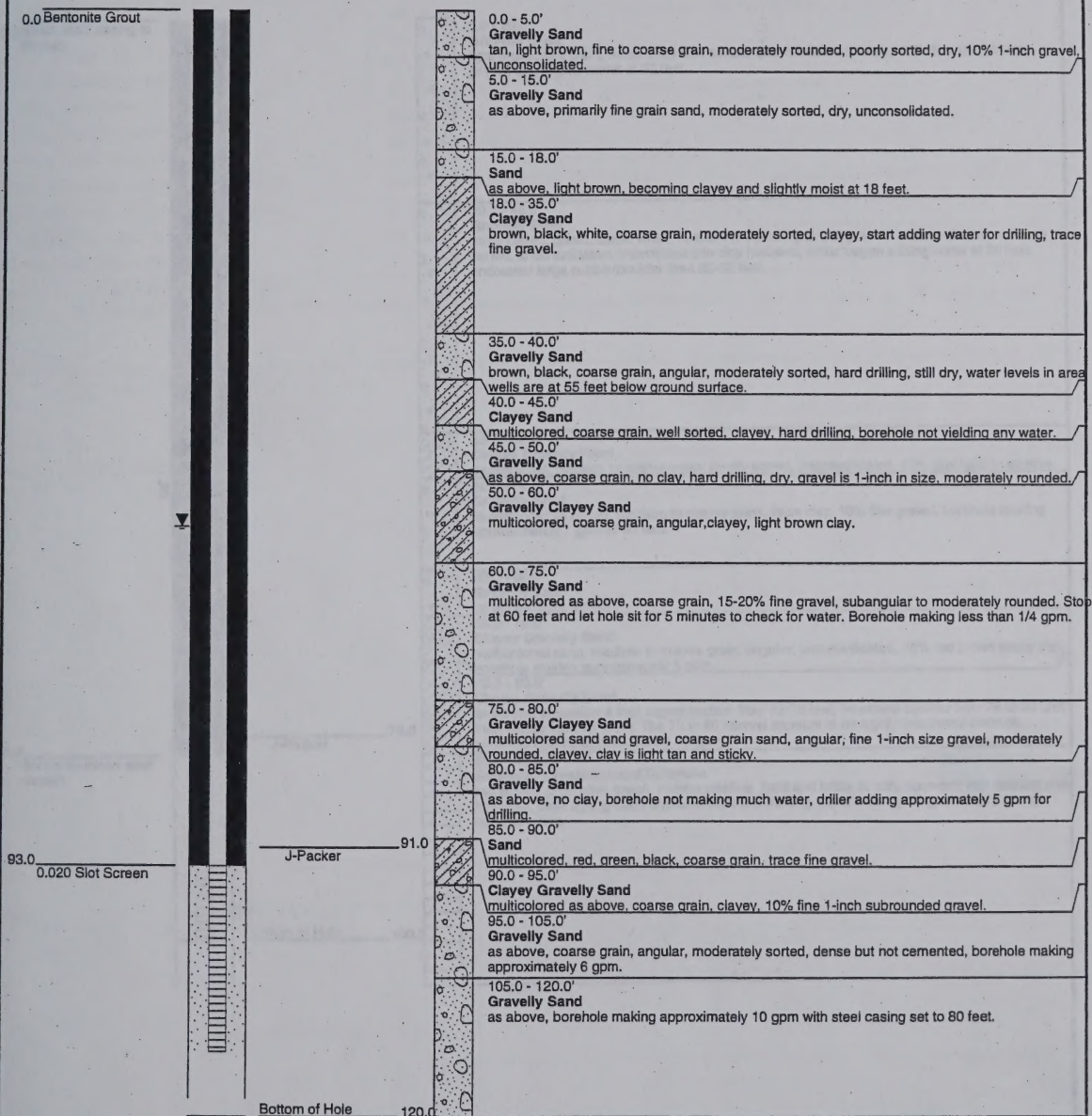
90.0 - 95.0' **Clayey Gravelly Sand**
multicolored as above, coarse grain, clayey, 10% fine 1-inch subrounded gravel.

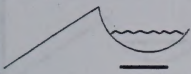
95.0 - 105.0' **Gravelly Sand**
as above, coarse grain, angular, moderately sorted, dense but not cemented, borehole making approximately 6 gpm.

105.0 - 120.0' **Gravelly Sand**
as above, borehole making approximately 10 gpm with steel casing set to 80 feet.

Well Construction Diagram

Geological Description





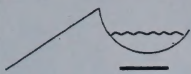
Well Construction Diagram

Geological Description

0.0 8-inch steel casing to
80 feet



0.0 - 20.0'	Gravelly Sand light brown, fine grain, moderately well sorted, unconsolidated, loose, 10% fine 1/4-3/4 inch gravel, dry, slightly moist at 20 feet.
20.0 - 45.0'	Gravelly Sand multicolored, green, black, white, medium to coarse grain, angular to subrounded, moderately sorted, unconsolidated, intermittent thin clay horizons, driller began adding water at 20 feet, encounter large cobble/boulder from 30-32 feet.
45.0 - 50.0'	Clayey Gravelly Sand multicolored, medium to coarse grain, poorly sorted, unconsolidated, 10% clay balls in sample.
50.0 - 60.0'	Gravelly Sand multicolored as above, medium to coarse grain, trace clay, 10% fine gravel, borehole making approximately 1 gpm at 60 feet.
60.0 - 65.0'	Gravelly Sand as above, 30% gravel.
65.0 - 70.0'	Clayey Gravelly Sand multicolored sand, medium to coarse grain, angular, unconsolidated, 10% red brown sticky clay, borehole making approximately 5 gpm.
70.0 - 80.0'	Clayey Gravelly Sand as above, encounter 4 foot clayey horizon from 72-76 feet, limestone boulder from 76 to 80 feet, then clayey from 78 to 80. The 72 to 80 interval appears to be highly weathered bedrock, borehole making approximately 10 gpm.
80.0 - 105.0'	Siltstone, Limestone and Dolomite red brown, grey, olive green, microcrystalline, hard and brittle to soft, abundant iron staining and hematite, trace light green claystone, borehole making approximately 10 gpm of very orange colored water.



HYDROMETRICS INC.

Consulting Scientists and Engineers
Helena, Montana

Recovery Well

Hole Name: HL-99-3

Date Hole Started: 6/17/99 Date Hole Finished: 6/23/99

Client: City of Helena

Project: Groundwater Remediation

County: Lewis and Clark State: Montana

Property Owner: City of Helena

Legal Description: SE,NW,SW Sec19, T10N, R3W

Descriptive Location: South of Bill Roberts
Golf Course

Recorded By: JR

Drilling Company: H&L Drilling

Driller: Mark Miller

Drilling Method: Air Rotary

Drilling Fluids Used: Water

Purpose of Hole: Install Recovery Well

Target Aquifer: Shallow Groundwater

Hole Diameter (in): 8

Total Depth Drilled (ft): 100

WELL COMPLETION	Y/N	DESCRIPTION	INTERVAL
Well Installed?	Y	8" steel to 80 feet, 5" screen 80 to 100', sump 100-105'	
Surface Casing Used?	N		
Screen/Perforations?	Y	0.020 slot stainless steel	80-100
Sand Pack?	N		
Annular Seal?	Y	Bentonite powder behind driven steel 0-80'	
Surface Seal?	N		
DEVELOPMENT/SAMPLING			
Well Developed?	Y	pumping at 40 gpm for 3 hours	
Water Samples Taken?	Y	volatile organics	
Boring Samples Taken?	N		

Static Water Level Below MP: 53.15

Date: 6/28/99

MP Description: top of steel casing

MP Height Above or Below Ground (ft): 1.52

Surface Casing Height (ft): 1.52

Riser Height (ft): 1.52

Ground Surface Elevation (ft): 3946.53

MP Elevation (ft): 3948.05

Remarks: N 506109.625 E 507616.831

Northing and Easting are based on City of Helena coordinate positions which are based on Mount Helena having coordinates N500000, E500000

WELL CONSTRUCTION

0.8-inch steel casing to
80 feet

80.0
5-inch stainless steel
screen

J-Packer

Bottom of Hole



GEOLOGICAL DESCRIPTION

0.0 - 20.0' **Gravelly Sand**
light brown, fine grain, moderately well sorted, unconsolidated, loose, 10% fine 1/4-3/4 inch gravel, dry, slightly moist at 20 feet.

20.0 - 45.0' **Gravelly Sand**
multicolored, green, black, white, medium to coarse grain, angular to subrounded, moderately sorted, unconsolidated, intermittent thin clay horizons, driller began adding water at 20 feet, encounter large cobble/boulder from 30-32 feet.

45.0 - 50.0' **Clayey Gravelly Sand**
multicolored, medium to coarse grain, poorly sorted, unconsolidated, 10% clay balls in sample.

50.0 - 60.0' **Gravelly Sand**
multicolored as above, medium to coarse grain, trace clay, 10% fine gravel, borehole making approximately 1 gpm at 60 feet.

60.0 - 65.0' **Gravelly Sand**
as above, 30% gravel.

65.0 - 70.0' **Clayey Gravelly Sand**
multicolored sand, medium to coarse grain, angular, unconsolidated, 10% red brown sticky clay, borehole making approximately 5 gpm.

70.0 - 80.0' **Clayey Gravelly Sand**
as above, encounter 4 foot clayey horizon from 72-76 feet, limestone boulder from 76 to 80 feet, then clayey from 78 to 80. The 72 to 80 interval appears to be highly weathered bedrock, borehole making approximately 10 gpm.

80.0 - 105.0' **Siltstone, Limestone and Dolomite**
red brown, grey, olive green, microcrystalline, hard and brittle to soft, abundant iron staining and hematite, trace light green claystone, borehole making approximately 10 gpm of very orange colored water.

APPENDIX B

EVALUATION OF MAXIMUM PUMPING RATES

Theis Drawdown Calculations

Theis Eqn:
$$s = \frac{Q}{4 \pi T} W(u) \quad u = \frac{r^2 S}{4 T t}$$

Where:

Well Name: HL-99-1
 S = Storage coefficient 1.60E-02
 T = Transmissivity 420 ft²/d
 r = Distance from the well 0.5 ft
 t = Time 14,000 days
 Q = Well Discharge 25 gpm
 $u = r^2 S / (4 T t)$ 1.70E-07
 W(u) = the "well function" 15.24
 s = Drawdown (calculated) 13.90 ft
 volume 504000

Total Pumping Rate: 95 gpm
 Total Drawdown at Well 1: 17.38 ft

Total well depth: 95 ft
 SWL: 55.69 ft
 Total Available DD: 29.31 ft (leaving 10 ft of water in well)
 Remaining DD: 11.93

Well Name: HL-99-2
 S = Storage coefficient #####
 T = Transmissivity 310 ft²/d
 r = Distance from the well 440 ft
 t = Time 14,000 days
 Q = Well Discharge 35 gpm
 $u = r^2 S / (4 T t)$ #####
 W(u) = the "well function" 1.66
 s = Drawdown 2.87 ft
 volume 705600

Well Name: HL-99-3
 S = Storage coefficient 1.60E-02
 T = Transmissivity 790 ft²/d
 r = Distance from the well 1000 ft
 t = Time 14,000 days
 Q = Well Discharge 35 gpm
 $u = r^2 S / (4 T t)$ 3.61E-01
 W(u) = the "well function" 0.91
 s = Drawdown (calculated) 0.62 ft
 volume 705600

Calibrate Transmissivity
 Using Results of
 Pumping Tests

Theis Drawdown Calculations

Theis Eqn:
$$s = \frac{Q}{4 \pi T} W(u) \quad u = \frac{r^2 S}{4 T t}$$

Where:

Well Name: HL-99-1
 S = Storage coefficient 1.60E-02
 T = Transmissivity 420 ft²/d
 r = Distance from the well 440 ft
 t = Time 14.000 days
 Q = Well Discharge 25 gpm
 u = $r^2 S / (4 T t)$ 1.31E-01
 W(u) = the "well function" 1.66
 s = Drawdown (calculated) 1.51 ft
 volume 504000

Total Pumping Rate: 95 gpm
 Total Drawdown at Well 1: 28.43 ft

Total well depth: 115 ft
 SWL: 57.01 ft
 Total Available DD: 47.99 ft (leaving 10 ft of water in well)
 Remaining DD: 19.56

Well Name: HL-99-2
 S = Storage coefficient #####
 T = Transmissivity 310 ft²/d
 r = Distance from the 0.5 ft
 t = Time 14.000 days
 Q = Well Discharge 35 gpm
 u = $r^2 S / (4 T t)$ #####
 W(u) = the "well function" 14.85
 s = Drawdown 25.68 ft
 volume 705600

Well Name: HL-99-3
 S = Storage coefficient 1.60E-02
 T = Transmissivity 790 ft²/d
 r = Distance from the well 560 ft
 t = Time 14.000 days
 Q = Well Discharge 35 gpm
 u = $r^2 S / (4 T t)$ 1.13E-01
 W(u) = the "well function" 1.82
 s = Drawdown (calculated) 1.24 ft
 volume 705600

Theis Drawdown Calculations

Theis Eqn:
$$s = \frac{Q}{4 \pi T} W(u) \quad u = \frac{r^2 S}{4 T t}$$

Where:

Well Name: HL-99-1
 S = Storage coefficient 1.60E-02
 T = Transmissivity 420 ft²/d
 r = Distance from the well 1000 ft
 t = Time 14.000 days
 Q = Well Discharge 25 gpm
 $u = r^2 S / (4 T t)$ 6.79E-01
 W(u) = the "well function" 0.428
 s = Drawdown (calculated) 0.39 ft
 volume 504000

Total Pumping Rate: 95 gpm
 Total Drawdown at Well 1: 12.67 ft

Total well depth: 105 ft
 SWL: 52.81 ft
 Total Available DD: 42.19 ft (leaving 10 ft of water in well)
 Remaining DD: 29.52

Well Name: HL-99-2
 S = Storage coefficient #####
 T = Transmissivity 310 ft²/d
 r = Distance from the well 560 ft
 t = Time 14.000 days
 Q = Well Discharge 35 gpm
 $u = r^2 S / (4 T t)$ #####
 W(u) = the "well function" 0.957
 s = Drawdown 1.66 ft
 volume 705600

Well Name: HL-99-3
 S = Storage coefficient 1.60E-02
 T = Transmissivity 790 ft²/d
 r = Distance from the well 0.5 ft
 t = Time 14.000 days
 Q = Well Discharge 35 gpm
 $u = r^2 S / (4 T t)$ 9.02E-08
 W(u) = the "well function" 15.65
 s = Drawdown (calculated) 10.62 ft
 volume 705600

Theis Drawdown Calculations

Theis Eqn:
$$s = \frac{Q}{4 \pi T} W(u) \quad u = \frac{r^2 S}{4 T t}$$

Where:

Well Name: HL-99-1
 S = Storage coefficient 1.60E-02
 T = Transmissivity 420 ft²/d
 r = Distance from the well 0.5 ft
 t = Time 180.000 days
 Q = Well Discharge 25 gpm
 $u = r^2 S / (4 T t)$ 1.32E-08
 W(u) = the "well function" 17.84
 s = Drawdown (calculated) 16.27 ft
 volume 6480000

Total Pumping Rate: 95 gpm
 Total Drawdown at Well 1: 25.53 ft

Total well depth: 95 ft
 SWL: 55.69 ft
 Total Available DD: 29.31 ft (leaving 10 ft of water in well)
 Remaining DD: 3.78

Well Name: HL-99-2
 S = Storage coefficient #####
 T = Transmissivity 310 ft²/d
 r = Distance from the well 440 ft
 t = Time 180.000 days
 Q = Well Discharge 35 gpm
 $u = r^2 S / (4 T t)$ #####
 W(u) = the "well function" 4.04
 s = Drawdown 6.99 ft
 volume 9072000

Well Name: HL-99-3
 S = Storage coefficient 1.60E-02
 T = Transmissivity 790 ft²/d
 r = Distance from the well 1000 ft
 t = Time 180.000 days
 Q = Well Discharge 35 gpm
 $u = r^2 S / (4 T t)$ 2.81E-02
 W(u) = the "well function" 3.35
 s = Drawdown (calculated) 2.27 ft
 volume 9072000

Determine Remaining
 Long-Term Drawdown
 Existing Conditions

Theis Drawdown Calculations

Theis Eqn:
$$s = \frac{Q}{4 \pi T} W(u) \quad u = \frac{r^2 S}{4 T t}$$

Where:

Well Name: HL-99-1
 S = Storage coefficient 1.60E-02
 T = Transmissivity 420 ft²/d
 r = Distance from the well 440 ft
 t = Time 180.000 days
 Q = Well Discharge 25 gpm
 u = $r^2 S / (4 T t)$ 1.02E-02
 W(u) = the "well function" 4.04
 s = Drawdown (calculated) 3.68 ft
 volume 6480000

Total Pumping Rate: 95 gpm
 Total Drawdown at Well 1: 37.43 ft

Total well depth: 115 ft
 SWL: 57.01 ft
 Total Available DD: 47.99 ft (leaving 10 ft of water in well)
 Remaining DD: 10.56

Well Name: HL-99-2
 S = Storage coefficient #####
 T = Transmissivity 310 ft²/d
 r = Distance from the well 0.5 ft
 t = Time 180.000 days
 Q = Well Discharge 35 gpm
 u = $r^2 S / (4 T t)$ #####
 W(u) = the "well function" 17.84
 s = Drawdown 30.85 ft
 volume 9072000

Well Name: HL-99-3
 S = Storage coefficient 1.60E-02
 T = Transmissivity 790 ft²/d
 r = Distance from the well 560 ft
 t = Time 180.000 days
 Q = Well Discharge 35 gpm
 u = $r^2 S / (4 T t)$ 8.80E-03
 W(u) = the "well function" 4.26
 s = Drawdown (calculated) 2.89 ft
 volume 9072000

Theis Drawdown Calculations

Theis Eqn:
$$s = \frac{Q}{4 \pi T} W(u) \quad u = \frac{r^2 S}{4 T t}$$

Where:

Well Name: HL-99-1
 S = Storage coefficient 1.60E-02
 T = Transmissivity 420 ft²/d
 r = Distance from the well 1000 ft
 t = Time 180.000 days
 Q = Well Discharge 25 gpm
 $u = r^2 S / (4 T t)$ 5.28E-02
 W(u) = the "well function" 2.47
 s = Drawdown (calculated) 2.23 ft
 volume 6480000

Total Pumping Rate: 95 gpm
 Total Drawdown at Well 1: 20.40 ft

Total well depth: 105 ft
 SWL: 52.81 ft
 Total Available DD: 42.19 ft (leaving 10 ft of water in well)
 Remaining DD: 21.79

Well Name: HL-99-2
 S = Storage coefficient #####
 T = Transmissivity 310 ft²/d
 r = Distance from the well 560 ft
 t = Time 180.000 days
 Q = Well Discharge 35 gpm
 $u = r^2 S / (4 T t)$ #####
 W(u) = the "well function" 3.35
 s = Drawdown 5.79 ft
 volume 9072000

Well Name: HL-99-3
 S = Storage coefficient 1.60E-02
 T = Transmissivity 790 ft²/d
 r = Distance from the well 0.5 ft
 t = Time 180.000 days
 Q = Well Discharge 35 gpm
 $u = r^2 S / (4 T t)$ 7.01E-09
 W(u) = the "well function" 18.2
 s = Drawdown (calculated) 12.35 ft
 volume 9072000

Theis Drawdown Calculations

Theis Eqn:
$$s = \frac{Q}{4 \pi T} W(u) \quad u = \frac{r^2 S}{4 T t}$$

Where:

Well Name: HL-99-1
 S = Storage coefficient 1.60E-02
 T = Transmissivity 420 ft²/d
 r = Distance from the well 0.5 ft
 t = Time 180.000 days
 Q = Well Discharge 20 gpm
 $u = r^2 S / (4 T t)$ 1.32E-08
 W(u) = the "well function" 17.84
 s = Drawdown (calculated) 13.01 ft
 volume 5184000

Total Pumping Rate: 140 gpm
 Total Drawdown at Well 1: 28.89 ft

Total well depth: 95 ft
 SWL: 55.69 ft
 Total Available DD: 29.31 ft (leaving 10 ft of water in well)
 Remaining DD: 0.42

Well Name: HL-99-2
 S = Storage coefficient #####
 T = Transmissivity 310 ft²/d
 r = Distance from the well 440 ft
 t = Time 180.000 days
 Q = Well Discharge 60 gpm
 $u = r^2 S / (4 T t)$ #####
 W(u) = the "well function" 4.04
 s = Drawdown 11.98 ft
 volume 1.6E+07

Well Name: HL-99-3
 S = Storage coefficient 1.60E-02
 T = Transmissivity 790 ft²/d
 r = Distance from the well 1000 ft
 t = Time 180.000 days
 Q = Well Discharge 60 gpm
 $u = r^2 S / (4 T t)$ 2.81E-02
 W(u) = the "well function" 3.35
 s = Drawdown (calculated) 3.90 ft
 volume 15552000

Maximize Pumping Rates
in Existing Wells

Theis Drawdown Calculations

Theis Eqn:
$$s = \frac{Q}{4 \pi T} W(u) \quad u = \frac{r^2 S}{4 T t}$$

Where:

Well Name: HL-99-1
 S = Storage coefficient 1.60E-02
 T = Transmissivity 420 ft²/d
 r = Distance from the well 440 ft
 t = Time 14.000 days
 Q = Well Discharge 20 gpm
 u = r²*S/(4Tt) 1.31E-01
 W(u) = the "well function" 1.66
 s = Drawdown (calculated) 1.21 ft
 volume 403200

Total Pumping Rate: 140 gpm
 Total Drawdown at Well 1: 47.35 ft

Total well depth: 115 ft
 SWL: 57.01 ft
 Total Available DD: 47.99 ft (leaving 10 ft of water in well)
 Remaining DD: 0.64

Well Name: HL-99-2
 S = Storage coefficient #####
 T = Transmissivity 310 ft²/d
 r = Distance from the 0.5 ft
 t = Time 14.000 days
 Q = Well Discharge 60 gpm
 u = r²*S/(4Tt) #####
 W(u) = the "well 14.85
 s = Drawdown 44.03 ft
 volume 1209600

Well Name: HL-99-3
 S = Storage coefficient 1.60E-02
 T = Transmissivity 790 ft²/d
 r = Distance from the well 560 ft
 t = Time 14.000 days
 Q = Well Discharge 60 gpm
 u = r²*S/(4Tt) 1.13E-01
 W(u) = the "well function" 1.82
 s = Drawdown (calculated) 2.12 ft
 volume 1209600

Theis Drawdown Calculations

Theis Eqn:
$$s = \frac{Q}{4 \pi T} W(u) \quad u = \frac{r^2 S}{4 T t}$$

Where:

Well Name: HL-99-1
 S = Storage coefficient 1.60E-02
 T = Transmissivity 420 ft²/d
 r = Distance from the well 1000 ft
 t = Time 14.000 days
 Q = Well Discharge 20 gpm
 u = r²*S/(4Tt) 6.79E-01
 W(u) = the "well function" 0.428
 s = Drawdown (calculated) 0.31 ft
 volume 403200

Total Pumping Rate: 140 gpm
 Total Drawdown at Well 1: 21.36 ft

Total well depth: 105 ft
 SWL: 52.81 ft
 Total Available DD: 42.19 ft (leaving 10 ft of water in well)
 Remaining DD: 20.83

Well Name: HL-99-2
 S = Storage coefficient #####
 T = Transmissivity 310 ft²/d
 r = Distance from the well 560 ft
 t = Time 14.000 days
 Q = Well Discharge 60 gpm
 u = r²*S/(4Tt) #####
 W(u) = the "well function" 0.957
 s = Drawdown 2.84 ft
 volume 1209600

Well Name: HL-99-3
 S = Storage coefficient 1.60E-02
 T = Transmissivity 790 ft²/d
 r = Distance from the well 0.5 ft
 t = Time 14.000 days
 Q = Well Discharge 60 gpm
 u = r²*S/(4Tt) 9.02E-08
 W(u) = the "well function" 15.65
 s = Drawdown (calculated) 18.21 ft
 volume 1209600

Theis Drawdown Calculations

$$\text{Theis Eqs: } s = \frac{Q}{4\pi T} W(u) \quad u = \frac{r^2 S}{4 T t}$$

Where:

Well Name: HL-99-1
 S = Storage coefficient 1.60E-02
 T = Transmissivity 429 ft²/d
 r = Distance from the well 0.5 ft
 t = Time 180,000 days
 Q = Well Discharge 15 gpm
 u = 2*S/(4T) 1.32E-04
 W(u) = the "well function" 17.84
 s = Drawdown (calculated) 9.78 ft
 volume 3888000

Total Pumping Rate 160 gpm
 Total Drawdown at Well 1: 28.92 ft

Total well depth: 95 ft
 SWL: 55.69 ft
 Total Available DD: 29.31 ft (leaving 10 ft of water in well)
 Remaining DD: 1.29

Well Name: HL-02-1
 S = Storage coefficient 0.000000
 T = Transmissivity 365 ft²/d
 r = Distance from the well 250 ft
 t = Time 180,000 days
 Q = Well Discharge 15 gpm
 u = 2*S/(4T) 0.000000
 W(u) = the "well function" 5.23
 s = Drawdown (calculated) 3.29 ft
 volume 3888000

Well Name: HL-99-2
 S = Storage coefficient 1.60E-02
 T = Transmissivity 310 ft²/d
 r = Distance from the well 440 ft
 t = Time 180,000 days
 Q = Well Discharge 40 gpm
 u = 2*S/(4T) 1.38E-02
 W(u) = the "well function" 4.04
 s = Drawdown (calculated) 7.98 ft
 volume 10368000

Well Name: HL-02-2
 S = Storage coefficient 1.60E-02
 T = Transmissivity 350 ft²/d
 r = Distance from the well 750 ft
 t = Time 180,000 days
 Q = Well Discharge 40 gpm
 u = 2*S/(4T) 2.27E-02
 W(u) = the "well function" 3.35
 s = Drawdown (calculated) 3.75 ft
 volume 10368000

Well Name: HL-99-3
 S = Storage coefficient 1.60E-02
 T = Transmissivity 790 ft²/d
 r = Distance from the well 1000 ft
 t = Time 180,000 days
 Q = Well Discharge 50 gpm
 u = 2*S/(4T) 2.81E-02
 W(u) = the "well function" 3.35
 s = Drawdown (calculated) 3.28 ft
 volume 12960000

Maximize Pumping Rates
 with 2 Additional Wells

Theis Drawdown Calculations

Theis Eqr:
$$s = \frac{Q}{4\pi T} \cdot W(u) \quad u = \frac{r^2 S}{4Tt}$$

Where:

Well Name: HL-99-1
 S = Storage coefficient 1.60E-02
 T = Transmissivity 420 ft²/d
 r = Distance from the well 440 ft
 t = Time 180,000 days
 Q = Well Discharge 15 gpm
 u = 2*S/(4T) 1.02E-02
 W(u) = the "well function" 4.04
 s = Drawdown (calculated) 2.21 ft
 volume 3888000

Total Pumping Rate: 160 gpm
 Total Drawdown at Well 1: 50.72 ft

Total well depth: 115 ft
 SWL: 57.01 ft
 Total Available DD: 47.99 ft (leaving 10 ft of water in well)
 Remaining DD: -2.73

Well Name: HL-02-1
 S = Storage coefficient 0.000000
 T = Transmissivity 365 ft²/d
 r = Distance from the well 250 ft
 t = Time 180,000 days
 Q = Well Discharge 15 gpm
 u = 2*S/(4T) 0.000000
 W(u) = the "well function" 5.23
 s = Drawdown 3.29 ft
 volume 3888000

Well Name: HL-99-2
 S = Storage coefficient 1.60E-02
 T = Transmissivity 310 ft²/d
 r = Distance from the well 0.5 ft
 t = Time 180,000 days
 Q = Well Discharge 40 gpm
 u = 2*S/(4T) 1.79E-08
 W(u) = the "well function" 17.84
 s = Drawdown (calculated) 35.26 ft
 volume 10368000

Well Name: HL-02-2
 S = Storage coefficient 1.60E-02
 T = Transmissivity 550 ft²/d
 r = Distance from the well 300 ft
 t = Time 180,000 days
 Q = Well Discharge 40 gpm
 u = 2*S/(4T) 3.63E-03
 W(u) = the "well function" 5.23
 s = Drawdown (calculated) 4.83 ft
 volume 10368000

Well Name: HL-99-3
 S = Storage coefficient 1.60E-02
 T = Transmissivity 790 ft²/d
 r = Distance from the well 560 ft
 t = Time 180,000 days
 Q = Well Discharge 50 gpm
 u = 2*S/(4T) 8.80E-03
 W(u) = the "well function" 4.26
 s = Drawdown (calculated) 4.13 ft
 volume 12960000

Theis Drawdown Calculations

$$\text{Theis Eqs: } s = \frac{Q}{4 \pi T} W(u) \quad u = \frac{r^2 S}{4 T t}$$

Where:

Well Name: HL-99-1
 S = Storage coefficient 1.60E-02
 T = Transmissivity 429 ft²/d
 r = Distance from the well 1000 ft
 t = Time 180,000 days
 Q = Well Discharge 15 gpm
 u = 2*S/(4Tt) 5.28E-02
 W(u) = the "well function" 2.47
 s = Drawdown (calculated) 13.6 ft
 volume 3888000

Total Pumping Rate: 160 gpm
 Total Drawdown at Well 1: 33.31 ft

Total well depth: 105 ft
 SWL: 52.81 ft
 Total Available DD: 42.19 ft (leaving 10 ft of water in well)
 Remaining DD: 8.88

Well Name: HL-02-1
 S = Storage coefficient #####
 T = Transmissivity 365 ft²/d
 r = Distance from the well 800 ft
 t = Time 180,000 days
 Q = Well Discharge 15 gpm
 u = 2*S/(4Tt) #####
 W(u) = the "well function" 2.96
 s = Drawdown 13.6 ft
 volume 3888000

Well Name: HL-99-2
 S = Storage coefficient 1.60E-02
 T = Transmissivity 310 ft²/d
 r = Distance from the well 560 ft
 t = Time 180,000 days
 Q = Well Discharge 40 gpm
 u = 2*S/(4Tt) 2.24E-02
 W(u) = the "well function" 3.35
 s = Drawdown (calculated) 5.62 ft
 volume 10368000

Well Name: HL-02-2
 S = Storage coefficient 1.60E-02
 T = Transmissivity 350 ft²/d
 r = Distance from the well 300 ft
 t = Time 180,000 days
 Q = Well Discharge 40 gpm
 u = 2*S/(4Tt) 3.63E-03
 W(u) = the "well function" 5.23
 s = Drawdown (calculated) 5.88 ft
 volume 10368000

Well Name: HL-99-3
 S = Storage coefficient 1.60E-02
 T = Transmissivity 790 ft²/d
 r = Distance from the well 0.5 ft
 t = Time 180,000 days
 Q = Well Discharge 50 gpm
 u = 2*S/(4Tt) 7.01E-09
 W(u) = the "well function" 18.2
 s = Drawdown (calculated) 17.62 ft
 volume 12960000



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